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COMMITTEE ON THE PEACEFUL
USES OF OUTER SPACE

INTERNATIONAL CO-OPERATION IN THE PEACEFUL USES OF OUTER SPACE - ACTIVITIES OF MEMBER STATES

Note by the Secretariat

Addendum

The present document contains information provided in replies received from Member States up to 14 December 1990.

UNITED STATES OF AMERICA

[Original: English]

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EXECUTIVE SUMMARY

In 1989, United States activity in space continued the national commitment to international co-operation in the peaceful uses of space, as it has done throughout its 31-year history. Since the beginning of the United States programme, NASA has conducted over 1,000 co-operative projects, both large and small, with over 130 foreign countries and international organizations. This year the National Oceanic and Atmospheric Administration (NOAA) celebrated the thirtieth anniversary of its inception. NOAA has a similar tradition of international co-operation in meteorological satellite activities.

Planetary science spearheaded accomplishments in 1989 with Voyager 2's exploration of Neptune and departure from the solar system and the launch of two probes, Magellan and Galileo, that began a new golden age of space science. Voyager 2's close-up view of Neptune showed a bright blue planet with winds of 1,500 miles per hour and six previously unknown moons.

Months before Voyager's main mission ended, the second phase of planetary exploration had begun. In May, the Space Shuttle deployed the Magellan spacecraft, which will map the surface of Venus. In October, the Galileo spacecraft began its roundabout trip to Jupiter, where it will drop a probe in the Jovian atmosphere in the first direct study of the solar system's largest planet. Galileo is a co-operative project with Germany. In November, the National Aeronautics and Space Administration (NASA) launched the Cosmic Background Explorer (COBE), an unmanned observer that will measure the cosmic radiation remaining from the "big bang" in hopes of developing a clearer picture of the early history of the universe. By the time the five-year golden age concludes, NASA will have launched 37 major science missions that may radically alter mankind's view of the universe.

In addition to the Magellan and Galileo science missions, NASA's five successful Space Shuttle missions in 1989 included deployment of a tracking and data relay satellite (TDRS) to complete the TDRS network. The United States is continuing its efforts to enhance the Shuttle system with work on an advanced solid rocket motor and the development of an extended duration orbiter, which will increase the Shuttle's on-orbit time from the current 7-day capability to an approximate 16-day capability.

1989 also marked the twentieth anniversary of the Apollo 11 Moon landing. President Bush announced on 20 July that it would be a goal of the United States to establish a permanent human presence on the Moon and use the experience gained there to begin human exploration of the planet Mars. In keeping with the United States' policy to foster international co-operation in civil space activities, the President requested that the National Space Council consider possibilities for international co-operation in achieving this goal. One of the central features of the President's vision is the International Space Station Freedom, a joint undertaking of Canada, the European Space Agency (ESA), Japan and the United States. In March, NASA signed a memorandum of understanding with the Government of Japan, completing the international agreements for the construction and use of Freedom.

In the area of space physics, NASA and ESA concluded an agreement for co-operation in the joint solar terrestrial science programme consisting of two missions - the Solar Heliospheric Observatory (SOHO) and Cluster. Experiments on the spacecraft will be provided by both United States and European scientists. NASA also signed a co-operative agreement with Japan in this area, approving the Geotail mission, which will make solar-terrestrial physics measurements.

In the area of Earth science, planning accelerated in 1989 for the international earth observing system (EOS), a corner-stone of the Mission to Planet Earth programme. A group of 41 instruments from the United States, Canada, Japan and Europe was selected for flight on EOS and over 500 scientists from 13 countries were identified to participate in the EOS programme.

Co-operation with the Union of Soviet Socialist Republics continued to progress in 1989, as well, in several areas. This co-operation was best highlighted by the telemedicine spacebridge for Armenia. The spacebridge, linking United States and Soviet hospitals, permitted medical consultation to assist with the longer-term consequences of the Armenian earthquake and injuries from the train explosion in Ufa. Later in the year, 29 NASA science experiments were flown on the Soviet Biosat mission Cosmos. These topics and other United States civil space activities in 1989 are the subject of the present report.

INTRODUCTION

The National Aeronautics and Space Act of 1958, as amended, governs United States civil programmes and activities to support research and development in the exploration of outer space. The Act designates NASA as the principal civilian agency responsible for the direction of United States aeronautical and space research programmes and associated activities.

NASA headquarters in Washington plans, co-ordinates and controls NASA programmes. The Space Science and Space Applications Boards of the National Academy of Sciences, the NASA Advisory Council and a number of more specialized panels provide guidance and recommendations to NASA. Research and development activities are concentrated at eight NASA field centres.

In April 1989, with the aim of bringing "coherence, continuity and commitment to the United States effort to explore, study and develop space", President Bush established the National Space Council under chairmanship of Vice President Dan Quayle. The role of the National Space Council is to co-ordinate United States civil, military and commercial efforts in space. The Council, as such, works in close co-operation with NASA.

NASA is required by law to conduct its activities "so as to contribute materially to ... co-operation by the United States with other nations and groups of nations". Since 1958, NASA has developed an extensive programme of international co-operation involving more than 130 nations and international organizations. These international projects are co-ordinated by the International Relations Division of NASA headquarters.

Other United States government agencies involved in, and providing support for, the United States civil space programme include parts of the Department of Commerce, and the Departments of Defense, Energy, State and Transportation. In addition, NASA assists the United States Agency for International Development (USAID) and co-operates with private United States firms in space-related activities.

The NOAA's National Environmental Satellite, Data, and Information Service (NESDIS) manages United States civil Earth-observing satellite systems, as well as global data bases for meteorology, oceanography, solid-earth geophysics and solar-terrestrial sciences. From these sources, NOAA develops and provides environmental data and information critical to weather forecasting, energy development, distribution of global food supplies and the development and management of natural resources.

The Department of Transportation has the responsibility to encourage, facilitate and co-ordinate the development of expendable launch vehicle operations by private United States firms.

I. NATIONAL SPACE POLICY

On 2 November 1989, President George Bush approved a national space policy that updates and reaffirms United States goals and activities in space. The updated policy is the result of a review undertaken by the National Space Council. The revisions clarify, strengthen and streamline selected aspects of the policy. Overall, the President's newly issued national space policy revalidates the ongoing direction of United States space efforts and provides a broad policy framework to guide future United States space activities.

The policy reaffirms the United States commitment to the exploration and use of space in support of its national and foreign policy goals. The policy also establishes the long-term goal of expanding human presence and activity beyond Earth orbit into the solar system. This goal provides the overall policy framework for the President's Space Exploration Initiative, announced on 20 July 1989, in which the President called for completing Space Station Freedom, returning permanently to the Moon and exploring the planet Mars.

II. SPACE FLIGHT

Assured access to space is a key element of the United States space programme and its internationally shared objective of continuing mankind's exploration of outer space. One of the primary goals of United States space transportation policy is to achieve and maintain safe and reliable access to transportation in and return from space. The United States national space transportation capability is based on a mix of vehicles, consisting of the space transportation system (STS), unmanned expendable launch vehicles (ELVs) and in-space transportation systems.

In 1989, the United States had five successful Space Shuttle flights and several successful ELV launches, including the November launch of COBE on the last NASA-owned Delta ELV. The use of ELVs and the reusable manned Space Shuttle reflect the United States strategy of employing a mixed fleet of space transportation systems in order to provide a resilient and flexible national space transportation capability now and in the future.

A. Space Shuttle

The Shuttle fleet is used to support selected research, development and critical programmes requiring manned presence and other unique Shuttle capabilities. With respect to United States Government-owned or operated ELV systems, policy holds that consistent with efforts to foster the development of a United States domestic launch services industry, NASA will procure required launch vehicle services directly from the United States private sector to the fullest extent feasible.

NASA's revitalized Shuttle fleet continued its success story in 1989 with five successful Shuttle missions. Included in these missions was the 13 March launch of Discovery (STS-29). The mission was highlighted by the successful deployment of

TDRS-D, completing the constellation known as the tracking and data-relay satellite system (TDRSS). TDRSS will increase communications, between Earth-orbiting spacecraft and a ground-based tracking station, from 15 to 85 per cent per orbit and facilitate a much higher rate of data flow. In addition, STS-29 carried several secondary payloads including the specially-designed IMAX camera, two student life-science experiments, a protein crystal growth experiment and a chromosome and plant cell division experiment.

Space Shuttle mission STS-30, Orbiter Atlantis' fourth flight, was launched on 4 May. The Atlantis crew successfully deployed the Magellan spacecraft, the first United States planetary spacecraft launched since Pioneer Venus in 1978 and the first planetary probe ever to be deployed from the Shuttle. Following its arrival at the planet Venus in August 1990, Magellan will map about 70 to 90 per cent of the surface of the planet, using for the first time a synthetic aperture radar instrument to create high-resolution images. Atlantis' secondary payloads included fluid research and electrical storm study experiments.

On 18 October, Orbiter Atlantis was launched again, on mission STS-34. The mission featured the deployment of the planetary probe Galileo, a United States-Federal Republic of Germany co-operative project. Galileo will make a six-year trip to Jupiter, the largest planet of the solar system. From there, the craft will transmit photos and information about Jupiter to Earth. STS-34 astronauts also conducted experiments regarding changes in the ozone layer and the impact of the state of weightlessness on the human body and on the growth of plants. Information gathered from both Magellan and Galileo will be made available to the international scientific community.

Shuttle capability and safety enhancement activities involving comprehensive review and testing of the entire Space Shuttle system, continued in 1989, including critical hardware, operations and programme organization. Numerous improvements were made to the orbiter fleet, including a new emergency crew egress system, enhanced landing and deceleration systems, safety modifications to the gaseous oxygen flow control valve, and the redesign of the orbiter 17-inch quick disconnect valve. Over 400 redesigns and other improvements were made to flight hardware components alone.

The new orbiter currently under construction, Endeavour, will incorporate even more improvements. Among these are a drag chute to allow contingency abort landings on relatively short runways as well as reduced rollout and brake/tire load, a 14-inch disconnect propellant coupling, an auxiliary power unit controller, a solid-state star tracker and an improved nose-wheel steering system. These measures will enhance performance, safety and facility of operations.

NASA has scheduled nine shuttle flights for 1990. A total of 63 flights are currently intended through 1995.

NASA will continue systematically to improve and enhance the Shuttle's safety margins and overall capabilities. NASA's long-term Shuttle recovery and improvement strategy features two major programmes now under way: the advanced solid rocket motor (ASRM) programme and the extended duration orbiter (EDO)

programme. Other system improvements are planned, such as extending the service life of the orbiter main engines, upgrading the flight computers and data management system, upgrading the braking systems, adding a third mobile launch platform and providing better total weather forecasting.

1. Advanced solid rocket motor

In March 1988, NASA submitted a plan to the United States Congress for the development of an ASRM, to replace the current solid rocket boosters by the mid-1990s. The ASRM design is targeted to achieve a 12,000 pound improvement in the Shuttle's payload lift capability. This increased capability will contribute significantly to an overall reduction in Shuttle transportation costs and will support deployment of Space Station Freedom and other critical projects. The ASRM programme is currently in the design and development phase. The first Shuttle flight using ASRM components is planned for early 1996.

In May 1989, NASA announced selection of Lockheed Missile Systems Division as the contractor to design, develop, test and evaluate the ASRM and to construct facilities for production and testing of the ASRM hardware. The contract is to cover the first 12 operational motors with an option for production of up to 44 motor sets. The NASA Marshall Space Flight Center has management responsibility for the ASRM and will directly manage performance of the contract. In June, engineers at Marshall tested candidate nozzle and insulation materials for the ASRM.

2. Extended duration orbiter

The EDO concept originates from the desire to enhance the scientific return from Shuttle flights by increasing the Shuttle's on-orbit time to 16 days from the current nominal 7-day capability. EDO is not a new orbiter, but is rather a set of modifications to existing orbiters. EDO will lengthen valuable on-orbit time not only for the conduct of science, but also for the maintenance and repair of orbiting spacecraft. It will also enable the accumulation of extended flight experience. To allow for the increased time on orbit, EDO will employ a cryogenic pallet, an upgraded waste management system, an enhanced regenerative carbon dioxide system and improved crew accommodations. Modification of one orbiter, Columbia, for the EDO capability is currently under way and will be completed by the end of 1991. The orbiter now under construction, Endeavour, is also designed to allow for EDO modification in the future if needs warrant. Sixteen-day flight duration will be built up to gradually, with 10- and 13-day missions prior to flight IML-2 (projected for January 1993), which will be the first 13-day EDO flight.

B. Expendable launch vehicles

ELVs are a reliable, proven means of space transportation. The mixed-fleet strategy recognizes the importance to the United States of utilizing ELVs to enhance access to space. The implementation of the United States Government

mixed-fleet strategy, along with measures to further the development of a United States commercial space launch industry, has resulted in significant changes to the NASA expendable launch vehicle programme. In accordance with national space transportation guidelines, United States government agencies will encourage, to the maximum extent feasible, a domestic commercial launch industry by contracting for necessary ELV launch services directly from the private sector. NASA will not maintain an ELV programme as an adjunct to the Space Shuttle. The United States Government fully endorses and will facilitate the commercialization of United States ELVs. It will also encourage free-market competition.

NASA successfully launched two ELVs in 1989. In September, a Navy communications satellite, FLEETSATCOM, was launched aboard an Atlas-Centaur vehicle. In November, a Delta vehicle launched and deployed COBE, which will measure faint cosmic background radiation. These launches were the last of the NASA-owned Atlas and Delta vehicles. The only ELVs remaining in NASA's inventory are six Scout vehicles, which will be launched up to the end of 1993. All other launches of NASA payloads on ELVs will now be procured from the Air Force (for Titan IV vehicles) or directly from commercial launch providers.

In the commercial sector, there were two successful orbital launches and one suborbital launch in 1989. United States commercial launch providers will continue to compete for launch contracts in an increasingly competitive global market.

C. Flight systems

1. Tethered satellite system

The tethered satellite system (TSS) is a co-operative programme between NASA and the Italian space agency, Agenzia Spaziale Italiana (ASI) designed to conduct unique science, an electrodynamic and later an atmospheric mission, in difficult to reach regions of space. The United States Space Shuttle will serve as a base from which the satellite system is deployed in an upward or downward mode, directly away or directly towards Earth, by an over 10-mile-long tether ("fishing reel"). NASA is responsible for development of the TSS "fishing reel" deployer and for overall systems integration. ASI is building the spherical, 1.6-metre diameter satellite that will be attached to the tether. Both countries will share the development of scientific instruments.

The first mission, TSS-1 (1991), will employ a 20 km conductive tether to study the generation of an electric current across the cord as it cuts across the Earth's magnetic field lines and the effects on the space plasma around the satellite and the orbiter while the current is varied. TSS-2 (planned for 1992), will use a 100 km non-conducting tether, deploying the research satellite downward, towards the Earth, in order to conduct investigations in atmospheric science, hypersonic aero-thermodynamics, and tether-initiated re-entry. The Memorandum of Understanding with Italy provides for planning two additional missions that are currently under consideration.

2. Orbital manoeuvring vehicle

A multi-purpose, unmanned, reusable "space tug", the orbital manoeuvring vehicle (OMV), as currently envisioned, will have the capability to deliver payloads to higher altitudes, refuel, reboost or reposition spacecraft and de-orbit spacecraft in a controlled manner in addition to performing other on-orbit servicing tasks. In this role, OMV will provide additional capability for the Space Shuttle and Space Station Freedom.

OMV's first flight will demonstrate the vehicle's capabilities and, as established in a co-operative agreement between NASA and Canadian Space Agency (CSA), carry out the Canadian "waves in space plasma" (WISP) science experiment. In conducting this experiment to measure the behaviour of radio waves in space and properties of the upper atmosphere, the OMV will work in conjunction with the Shuttle over a distance of up to 100 km. Now in the development stage, the OMV project is managed by the Marshall Space Flight Center with TRW, Inc. as the prime contractor.

3. Spacelab

Spacelab, a science observatory and laboratory facility carried to and from orbit in the Shuttle's payload bay, provides an on-orbit capability for manned interactive science. The Spacelab facility was jointly developed with ESA to serve as an integral part of the Space Shuttle system. ESA developed and built the pressurized lab module providing a "shirtsleeve" environment for the crew, an unpressurized platform pallet and igloo systems and an instrument pointing system. NASA is currently developing a new pallet system to allow for mixed cargo arrangements. Eight missions (three module and five pallet missions) were flown from 1981 to 1986. Spacelab flights are scheduled to resume in 1990 beginning with the first flight of the Astrophysics Spacelab (ASTRO-1). In all, over 30 Spacelab missions, including 10 missions employing the pressurized module, are planned from 1990 to 1994.

During 1989, the Spacelab hardware continued to be recertified to ensure the readiness of all hardware elements for future Shuttle flight. Changes and improvements resulting from the recertification activity are currently being implemented. In addition, a computer specifically designed for Spacelab that will improve its computer reliability is expected to be ready for flight in 1990.

Continuing the tradition of international participation in the Spacelab programme and missions, nearly all of the Spacelab flights scheduled in 1990 and 1991 are multinational in nature. The Spacelab life sciences mission SLS-1, which is scheduled for late 1990, will be the first Spacelab mission dedicated to life sciences research. The SLS series was proposed by a team of international investigators, including Swiss and Australian as well as United States life scientists. In July 1989, NASA and the Federal Republic of Germany's Ministry for Research and Technology (BMFT) signed a Memorandum of Understanding to launch German Spacelab payloads on the Space Shuttle.

Other international Spacelab missions scheduled for the 1990-1992 time-frame include: (a) the first international microgravity laboratory (IML-1), composed of facilities developed by ESA, the French National Centre for Space Studies (CNES), the German Aerospace Establishment (DLR), the National Space Development Agency of Japan (NASDA), and the National Research Council of Canada (NRCC); (b) Spacelab-J, sponsored by NASA; and (c) Spacelab D-2, the follow-on mission to the 1985 Spacelab D-1 mission, which is sponsored by the Federal Republic of Germany's Ministry for Research and Technology (BMFT).

D. Advanced transportation systems

1. Advanced programmes

NASA conducts concept feasibility and selected systems definition and preliminary design studies and related advanced development on a continual basis to provide the technical and programmatic data to identify evolving space transportation system requirements and to evaluate new space transportation initiatives. This involves the conceptual definition of the future space transportation systems architecture and specific elements needed over the next 20 years. Advanced programmes activity and studies support major NASA programmes and systems, such as OMV, the TSS, the Space Shuttle and Space Station Freedom.

As the present Space Shuttle orbiters will near the end of their operational lifetime in the 2005-2010 time-frame, consideration of the next manned transportation system becomes appropriate. Goals for any such transportation system would be to meet people/payload requirements, improve cost-effectiveness and increase system reliability and performance margins. NASA is currently examining three alternative paths: Shuttle evolution, a personnel launch system (PLS) and an advanced manned launch system (AMLS). A new system (such as PLS or AMLS) would offer significantly improved capabilities and future potential but would require 10 years to build at considerable expense. Evolving the current system would offer more timely and affordable improvements but would be limited in scope to the potential of the Space Shuttle envelope.

In 1989, the advanced programmes activity in support of the evolving and future space transportation capability focused on four major areas - advanced transportation, advanced operations support, satellite servicing and advanced missions. Advanced transportation study efforts focused on cargo vehicles, manned vehicles and space transfer vehicles. The new programme emphasis on advanced operations support systems addresses the effectiveness of operations as the key parameter in improving safety as well as reducing life-cycle costs for space transportation and orbital systems. The satellite servicing effort encompasses on-orbit servicing systems and transportation-related tether applications. This effort focuses on the definition of systems and procedures that utilize Shuttle capabilities and are compatible with the Space Station Freedom.

Advanced mission activities will continue to focus, with expanded scope and increased depth, on potential manned and unmanned missions beyond Space Station Freedom, with particular attention to the space transportation requirements. In

addition, definition studies for a potential crew emergency return vehicle (CERV) are continuing. CERV is an essential component to the NASA goal of assured crew return capability to respond to possible Space Station emergencies in the future.

2. Shuttle-C (cargo) studies

In 1989, NASA continued definition studies of an unmanned version of the Space Shuttle, termed Shuttle-C (cargo), capable of delivering 100,000 to 170,000 pounds of usable cargo into low-earth orbit. This vehicle, if developed, could provide the capability to satisfy potential heavy-lift launch requirements from 1994 until the advanced launch system (ALS) becomes available. At the core of the Shuttle-C design philosophy is the principle of enhancing the existing STS. This will hold down costs by taking maximum advantage of existing designs and facilities and will extend the life of the current Space Shuttle fleet. The number of launches needed to perform a number of high-priority space missions would be reduced. Launches and assembly time for Space Station Freedom, for example, could be cut in half. Besides Space Station assembly, other potential Shuttle-C applications include planetary missions, a test-bed for new systems as well as missions to geosynchronous and polar orbits.

The Shuttle-C concept involves replacing the Shuttle orbiter with a cargo canister. In addition to building upon the accumulated experience of the Shuttle system, Shuttle-C would use mature elements, including the solid rocket boosters, external tanks, launch infrastructure and thrust and propulsion systems. As a result the concept is capable of comparatively low-risk, near-term development and deployment. Shuttle-C further offers the benefit of carrying into orbit one and half to two and a half times more cargo per launch than can be lifted using existing United States space transportation capability. NASA has selected a contractor team to continue Shuttle-C studies and has initiated programme definition, targeting for new start approval in the near future.

3. Advanced launch system

The ALS programme, a joint Department of Defense-NASA effort, continued in 1989 with concept definition for a family of launch vehicles and with technology development and demonstration and preliminary design activities. The long-term goal of the programme is a family of vehicles with significantly improved operational characteristics in the areas of cost, responsiveness, reliability and resiliency. The primary focus has been on a heavy-life vehicle with a payload capacity to low-earth orbit in the range of 100,000 to 200,000 pounds, to become operational after the year 2000. NASA is responsible for the ALS-focused technology development with specific emphasis on propulsion system development and the programme's unique civil requirements. NASA has begun using computational fluid dynamics and computational simulation to explore further propulsion studies.

4. National Aerospace Plane

The National Aerospace Plane (NASP) programme is a joint NASA-Department of Defense programme designed to develop the new technologies for reusable, single-stage-to-orbit vehicles that have air-breathing primary propulsion and also take-off and land via a runway. The effort could culminate in the flight test of an experimental vehicle, the X-30, to demonstrate the successful integration of all the advanced technologies.

Following a review by the National Space Council in 1989, the President endorsed the programme with a schedule revised to extend to 1993 the current period of technology development that must precede development of any flight vehicle. Current work is making significant progress in key areas of propulsion, materials, aerodynamics and computational fluid dynamics. Operational vehicles, based on such technology, could revolutionize space transportation by putting payloads into orbit more quickly and more efficiency than conventional rocket-booster systems.

5. Solid propulsion integrity programme

The solid propulsion integrity programme originated from joint NASA-Department of Defense-industry studies in 1984 which identified critical shortfalls in the United States engineering technology base for solid-fuel rocket motors. The objective of the programme is to provide NASA engineers with the techniques, engineering tools and computer programs to be able to renew and strengthen engineering capability in solid propulsion technology and manufacturing. This collaborative effort of NASA, the Department of Defense and industry is examining materials, design tools, processing and controls and inspection techniques. The programme has recently been expanded to include bondline and increased nozzle work as well as composite materials. Testing began in the spring of 1989 at NASA's Marshall Space Flight Center with the important firing of a 26-foot long, 100,000 pound thrust solid rocket motor.

E. Orbital debris

The success of a space programme depends upon a space environment sufficiently free of debris to enable safe and dependable operation of manned and unmanned spacecraft. In February of 1989, the National Security Council released the Interagency Group (Space) report on orbital debris. This report, of which NASA, the Defense Department and the Department of Transportation were the primary authors, was the result of a six-month inter-agency study called for in the 1988 United States national space policy.

The key conclusions of the report were that:

(a) If no actions were taken, the debris environment might substantially threaten the safe and reliable operation of manned and unmanned space activities;

(b) All future space activities and space hardware should include operational and design considerations to reduce debris creation;

(c) A comprehensive research and development plan for improving debris monitoring, modelling and data management should be conducted;

(d) With input from the private sector, a basic research plan for technologies and procedures for minimizing and surviving debris should be produced.

The report instructed NASA, the Department of Defense and the Department of Transportation jointly to formulate an orbital debris research plan to address the third and fourth conclusions. The plan, which outlines specific research efforts each agency will undertake in the area of orbital debris and the funding requirements for those efforts, is now in final preparation for presentation to the National Space Council in 1990.

In addition, the report identified the need for international discussions and co-operation as important ingredients of any viable orbital debris strategy and policy. It was recognized that the United States cannot fully address the orbital debris issue without the co-operation of other nations.

To that end, NASA has actively initiated bilateral dialogues with other space-faring nations, to apprise them of current United States research on debris and to learn more about their own efforts in this area. During the course of 1989, NASA representatives briefed ESA and the space agencies of Australia, Canada, the Federal Republic of Germany, France, India, Japan and the Soviet Union on the contents and conclusions of the report on orbital debris.

ESA, which has established its own Orbital Debris Working Group, has participated in co-ordination meetings on debris issues with NASA scientists on a roughly biannual basis for the last three years. The objective of these meetings is the exchange of information and the identification of potential areas of co-operation that would be mutually beneficial. NASA and ESA are currently examining possibilities for scientific dialogue and exchange of research materials on orbital debris.

In August 1989, NASA reached a co-operative agreement with BMFT of the Federal Republic of Germany to begin a joint debris imaging activity and for the exchange of orbital debris data. Further co-operative activities between NASA and BMFT in this area are planned for 1990. Also in 1989, NASA scientists held informal discussions on debris issues with the French space agency CNES. A topic of particular interest in these discussions was the passivation of ELV upper stages to reduce the risk of debris-creating on-orbit explosions; this is already done by the United States with the upper stage of the Delta vehicle. Partly as a result of these discussions with NASA, in 1989, CNES and Arianespace redesigned the Ariane 4 rocket upper stage used for polar orbit launches, to vent pressurants and propellants and thereby prevent explosions and resultant orbital debris.

III. INTERNATIONAL SPACE STATION FREEDOM

Space Station Freedom is the largest co-operative civil science and technology project ever undertaken. Space Station Freedom will be constructed, operated, and used by all of its partners to conduct scientific experiments and develop new technologies; as an observatory to view the Earth, the solar system and the universe; as a transportation node to assemble and deploy payloads and vehicles; as a servicing facility to maintain and repair payloads and vehicles; and as a unique commercial research and manufacturing facility. Its permanently manned base will also become a stepping stone for human exploration of the solar system beyond Earth's orbit.

The Space Station complex will have manned, man-tended and unmanned elements. It will consist of a core station in low-Earth orbit together with various flight and infrastructure facilities. The United States will provide the infrastructure, an attached habitation module, an attached laboratory module and an unmanned polar orbiting platform. ESA will furnish an attached pressurized laboratory module, a polar orbiting platform and a man-tended free-flying platform. Japan will provide a research and development laboratory composed of a pressurized module and a space-exposed facility and Canada will provide a mobile servicing system to be used in Station assembly, operation and maintenance.

On 29 September 1988, in Washington, the United States and its partners signed the multilateral Agreement among the Government of the United States of America, Governments of the member States of the European Space Agency, the Government of Japan, and the Government of Canada on Co-operation in the Detailed Design, Development, Operation and Utilization of the Permanently Manned Civil Space Station. At the time of the signing, the participating countries of the Space Station Freedom programme were Belgium, Canada, Denmark, the Federal Republic of Germany, France, Ireland, Italy, Japan, the Netherlands, Norway and Spain. The Agreement provides the intergovernmental policy direction for the international aspects of the Space Station Freedom programme. On the same date, NASA signed bilateral memoranda of understanding with its co-operating partners in Canada and Europe (the Canadian Ministry of State for Science and Technology and ESA, respectively). A comparable memorandum with the Government of Japan was signed on 14 March 1989. The memoranda provide the technical and programmatic details of the international aspects of the Space Station Freedom programme.

On 28 June 1989, NASA's Office of Space Science and Applications announced the selection of 27 flight experiments, or concept studies leading to experiments, that will fly aboard the Space Station Freedom as attached payloads. The investigations include participants from 50 organizations representing NASA and other government and private research centres, United States universities and five foreign countries. The selected experiments and concepts represent a wide range of scientific disciplines and involve nearly 130 scientists.

The EOS programme, a multi-mission observation system of the 1990s to study global changes taking place in planet Earth's environment, will make use of the polar platforms being developed as part of the Space Station Freedom programme.

Currently, the United States and its international partners have entered into the detailed design and development phase of the co-operation. It is estimated that launch of the first element of the Space Station will be in March of 1995.

IV. SPACE SCIENCE AND APPLICATIONS

A. Astrophysics

Mankind's thoughts about the long-term future of the human race involve fundamental questions about the nature of the cosmos - its past and its future, its governing physical laws, its harsh explosions and its potential for hospitable planetary systems. Astronomical discoveries have been occurring at a quickening pace since the development of the first telescope and particularly in the past few decades.

The placement of powerful new telescopes in space, outside Earth's atmosphere, has greatly enhanced observational capability. The purpose of NASA's astrophysics programme is to examine the universe in all the wavelengths of the electromagnetic spectrum, from the shortest gamma rays to the longest radio waves, in an effort to understand its origin, processes and evolution.

1. Supernova 1987A

A host of nations have carried out observations of supernova 1987A, which is 160,000 to 170,000 light years away, since its discovery in February 1987. Supernova 1987A is the closest observable supernova in 400 years. As one of the most powerful events in nature, supernovae are significant because they represent the deaths of stars and because they are believed to be the locations where nature generates the heavier elements (e.g., iron) from the lighter elements (e.g., carbon), in a process called "nucleosynthesis". They are also thought to be the primary source of cosmic rays, the birthplace of neutron stars and stellar black holes, and are studied in their own right as a frequent point along the path of stellar evolution.

NASA's strategy has been to implement immediate post-explosion phase studies across the full range of the electromagnetic spectrum, to be followed by supernova examinations from NASA's space-based great observatories as they are launched throughout the coming decade.

In the ultraviolet portion of the spectrum, observations have been made by the International Ultraviolet Explorer (IUE), a co-operative project of NASA, ESA and the United Kingdom Science and Engineering Research Council (SERC) as well as via the United States Voyager spacecraft and a series of rocket campaigns launched by NASA from Australia. These ultraviolet spectral studies are still continuing. Infra-red studies have been made by NASA's C-141 Kuiper Airborne Observatory from New Zealand. The Kuiper team continued in 1989 its studies of charged (ionized) particles and mass and ejection velocities of heavy metals from the inner layers of the supernova.

In the hard X-ray spectral region, NASA continued studies using instruments on balloons launched from Alice Springs, Australia. Other X-ray data were obtained for international study using the USSR's Mir space station. Recently, NASA has reconfigured its ASTRO-1 Spacelab mission to include the broad-band X-ray telescope (BBXRT), which is capable of greater sensitivity in the soft X-ray region than were the NASA balloon campaigns. ASTRO-1 is scheduled to be deployed from the Space Shuttle in mid-1990.

Gamma-ray emissions from the supernova were also monitored by a variety of instruments, including those on the United States solar maximum mission and balloon platforms launched from Australia. These gamma-ray studies uniquely identified the radioactive isotopes synthesized in the explosion. In particular, their identification of the presence of 77-day isotope cobalt 57 has provided, for the first time, an independent confirmation of the correctness of our present-day understanding of the physical processes underlying stellar explosions and element synthesis.

2. Galactic centre annihilation source

The recent NASA supernova 1987A campaigns have provided an unexpected return. High resolution gamma-ray observations indicate that a variable source of the annihilation-of-positrons gamma-ray spectral line located within a few degrees of the Milky Way galaxy's galactic centre may have "turned on" once again. This source was active in the 1970s and appeared to become latent early in 1980. It was not detected in balloon campaigns in 1981 and 1984. Data from the solar maximum mission, however, suggest the gamma radiation may emanate from a diffuse galactic source more or less permanently present, plus a variable discrete source or sources located near the centre. The supernova balloon campaigns of 1988 and 1989 included instrumentation that may permit the source of this radiation to be identified. Verification missions continued in 1989. Both foreign and United States universities continue to analyse the resulting information.

3. Great observatories

The 20 years between the late 1960s and the late 1980s were a pioneering era for space-based astrophysical observation. The next generation of space observatories will usher in a "golden age" in which astronomical studies will be conducted by space-based observatories with a sensitivity and resolution far superior to the capabilities of their predecessors. Astrophysics research for the next 20 years will benefit from a set of complementary and contemporaneous space observatories dedicated to the study of separate portions of the electromagnetic spectrum: the Hubble Space Telescope (HST) which will make optical and ultraviolet observations, the gamma-ray observatory (GRO), the advanced X-ray astrophysics facility (AXAF) and the space infra-red telescope facility (SIRTF). Together, the components of this multispectral campaign will enable scientists to see farther into the universe, and in greater detail, than ever before.

Hubble space telescope

The NASA/ESA HST, scheduled for launch from the space shuttle in April 1990, is the first large international optical telescope to be permanently stationed in low Earth orbit. HST has a tremendous potential for fundamental scientific breakthroughs in astronomy. When placed in orbit, HST will enable astronomers to observe the visible universe with a clarity many times greater than the most powerful ground-based telescopes, as well as to penetrate deep into the universe in the ultraviolet and infra-red regions (1,200-11,000 A) adjacent to the visible portion of the electromagnetic spectrum. HST is also the first spacecraft designed for routine on-orbit servicing by the Space Shuttle crew.

In 1989, the Space Telescope Science Institute in Baltimore, Maryland, completed selection of the first science observation proposals from the astronomy community for observations to be carried out using HST. Among the accepted proposals are plans to search for black holes in neighbouring galaxies, to survey the dense cores of globular star clusters, to see better the most distant galaxies in the universe, to probe the mysterious core of the Milky Way galaxy and to search for the nature of the objects that may trigger bizarre gamma-ray bursts. One hundred and sixty-two proposals were accepted following an intensive scientific peer review of 556 proposals submitted by astronomers from 30 countries. Several of the investigative teams selected for use of the telescope were composed of both United States and foreign investigators. In all, roughly 75 per cent of all investigators were from the United States and roughly 25 per cent were foreign (20 per cent being European). Information derived from HST will be available to the international community.

Gamma-ray observatory

NASA's 17-ton GRO is scheduled for launch from the Space Shuttle in November 1990. Because the universe is largely transparent to the transmission of gamma rays, GRO will be able to probe the centre of the Milky Way galaxy for the first time. It may also be able to identify black holes by measuring the characteristic gamma radiation emitted from their surrounding material and to identify the presence of "anti-matter" through the characteristic gamma-ray signature of its annihilation caused by encounters with normal matter. GRO is designed for orbital refuelling, so its operational lifetime could potentially extend well beyond the turn of the century.

GRO will carry four instruments on board with investigators from the United States, ESA, the Federal Republic of Germany and the Netherlands. The Federal Republic of Germany is furnishing a major, complex scientific instrument (COMPTEL) for GRO as well as key portions of a second instrument, the Explorer gamma-ray experiment telescope (EGRET). The United States is furnishing the oriented scintillation spectrometer experiment (OSSE), as well as the burst and transient shuttle experiment (BATSE).

Advanced X-ray astrophysics facility

AXAF, currently under development, will be one of the largest scientific satellites ever flown, measuring approximately 14 feet in diameter and 45 feet in length, with six pairs of nested grazing incidence mirrors. AXAF will be designed for on-orbit maintenance to extend its life and upgrade its scientific capability. It will be used by the international scientific community in conjunction with NASA for approximately a 15-year period to examine the X-ray region of the electromagnetic spectrum. AXAF will have 1,000 times the capacity for spectroscopy of any of any previous X-ray mission. Scientists from the United Kingdom and the Netherlands will join United States participants in designing experiments for AXAF. NASA is responsible for development of AXAF, with one instrument, the low-energy transmission grating spectrometer, being built by the Netherlands. AXAF is currently scheduled for launch in 1997.

Space infra-red telescope facility

SIRTF, building on the tradition of the infra-red astronomy satellite (IRAS), is being designed for astronomy in the infra-red portion of the electromagnetic spectrum. The project, currently still in the conceptual design phase, has recently been modified for a high-altitude circular orbit mission. SIRTF, the last of the great observatories, is tentatively planned for launch in the late 1990s.

SIRTF, capitalizing on advances in United States sensor technology since IRAS, will offer greater operational flexibility and sensitivity. It will investigate the "cool" regions of the universe, where dust and cosmic gas condense into new stars and "cool" objects, such as asteroids, comets and planetary systems, all with an unprecedented spectral and spatial infra-red resolution. SIRTF will also have a significantly longer lifetime than IRAS: it is designed to be in operation for at least 5 years in contrast to IRAS' 10-month lifetime.

4. Explorer satellites

International ultraviolet explorer

IUE is a joint project of NASA, ESA and SERC. Now in its twelfth year of operation, IUE has become one of the most productive telescopes in existence and has provided the world's astronomers with a vast amount of important astronomical information. IUE investigators have produced more than 1,500 scientific papers.

IUE has made some of the most significant discoveries in modern astronomy, such as the discovery of galactic haloes and the monitoring of the ultraviolet emissions from supernova 1987A. More recently, in 1989, the Explorer made important observations of emissions from the white-dwarf star 0950+139, previously thought to be inactive. IUE remains in constant use, operated jointly by ESA and NASA.

Cosmic Background Explorer

On 18 November 1989 NASA launched COBE from Vandenberg Air Force Base in California aboard a Delta ELV. Circling the globe in a polar orbit, the 5,000 pound spacecraft is measuring the cosmic submillimetre radiation remaining from the "big bang" in the hopes of developing a clearer picture of the early history of the universe. By measuring the diffuse infra-red radiation (cosmic background) that bombards the Earth from every direction, COBE's instruments will help to clarify such matters as the nature of the primeval explosion, which started the expansion of the universe and made it uniform and the processes leading to the formation of galaxies.

COBE carries three infra-red and microwave-measuring instruments that will map the entire sky twice during its one-year mission. The differential microwave radiometer (DMR) is measuring the best evidence of the primeval explosion, the sky's seemingly uniform background glow of radiation that emanates from every direction. Different parts of the background radiation are expected to have different degrees of brightness if the "big bang" contained the density fluctuations that led to the formation of galaxies. The far infra-red absolute spectrophotometer (FIRAS) will determine if the cosmic background radiation has the expected spectral intensity at each wavelength. Discrepancies could indicate that other sources of radiation, such as galaxies, existed shortly after the formation of the universe, in addition to the "big bang" radiation. The diffuse infra-red background experiment (DIRBE) may be able to detect the faint glow marking the formation of the earliest stars and galaxies. DIRBE is so precise that it can measure the glow from ancient stars and galaxies, even if it is only one per cent as bright as our local celestial environment. Together, data from these instruments should provide scientists with new insights into the origin and evolution of the universe.

Small-class Explorers

Fifty-one proposals were received in the fall of 1988 for small-class Explorer missions covering the scientific disciplines of infra-red and submillimetre astronomy, visible and ultraviolet astronomy, X-ray and gamma-ray astronomy, space plasma physics, solar physics, cosmic-ray physics and upper atmospheric research. These proposals were for missions that could be launched within three years of selection, having less than 225 kilogram mass and costing less on average than $30 million.

In 1989, from among the 51 candidate missions, the following were chosen: the Solar, Anomalous and Magnetospheric Particle Explorer (SAMPEX) and the Fast Auroral Snapshot Explorer (FAST). Both of these small explorers are designed for research in solar-terrestrial physics. A third mission, the short-wave astronomical satellite (SWAS), will undertake infra-red astronomy measurements.

5. ROSAT

ROSAT (short for "Roentgensatellit") is a co-operative venture of the Federal Republic of Germany's BMFT and NASA. The purpose of the ROSAT mission is to study X-ray emissions from non-solar celestial objects with pointing capability to observe specific X-ray sources. BMFT is providing the spacecraft and telescope. NASA is providing an instrument, the high resolution imager, and the launch. The United Kingdom, through a separate bilateral arrangement with the Federal Republic of Germany, is providing an extreme ultraviolet (EUV) wide-field camera. All of ROSAT's instruments have been constructed, and it is currently planned for a June 1990 launch aboard a Delta-II ELV.

ROSAT's mission is scheduled for three years. The first six months will be dedicated to an X-ray survey of the entire sky, which is expected to identify many previously unknown X-ray sources. For the remaining two and a half years, ROSAT will use its pointing capability to perform detailed studies of approximately 10,000 X-ray objects, including the coronas of stars of all spectral types, supernova remnants and X-ray-emitting clusters of galaxies. ROSAT could also help to reveal the origin of the X-ray glow suffusing the universe.

6. Infra-red astronomy satellite

IRAS was a collaborative project among the United States, the Netherlands and the United Kingdom. Launched in 1983, IRAS scanned more than 90 per cent of the sky in four infra-red bands over a period of 300 days. Data from the IRAS mission have led to a number of the most important discoveries of the "cooler" features of the universe, including the possible existence of a planetary system circling the star Vega and several other nearby stars, bands of dust in our solar system (apparently the result of collisions between asteroids) and a collapsing dust cloud that astronomers predict should become a star in about 100,000 years.

Data from IRAS continue to be analysed up to the present by astronomers from the international community. Of most interest has been the discovery of ultraluminous infra-red galaxies. The IRAS data have suggested that the formation of very luminous quasars may be related to the evolution of ultraluminous infra-red galaxies.

7. White-dwarf star 0950+139

Astronomers at the Space Telescope Science Institute, which is sponsored by NASA, reported unanticipated gas emissions from a "white-dwarf" star in early 1989. White dwarfs have been thought to mark the end of some stars' lifespans, precluding such emissions. This white dwarf star, catalogued as 0950+139, lies at the centre of a faint nebula called EGB 6 and is located about 1,500 light-years from Earth in the direction of the constellation Leo. The nebula was formed an estimated 50,000 years ago when the star was in the red giant stage, which occurs late in a star's evolution. When red giants subsequently exhaust their nuclear fuel and "burn out", they contract to become white dwarfs.

Astronomers commonly believe that white-dwarf stars mark the end of any further stellar activity other than a gradual cooling off over billions of years. The researchers found, however, that 0950+139 is surrounded by a glowing cloud of gas about the size of our own solar system. The star has very recently shed additional gas long after entering the white-dwarf stage, and it is believed to have undergone additional mass loss.

8. FUSE and ACE explorers

In the fall of 1989, NASA authorized further development for two unmanned scientific spacecraft that would explore interplanetary space and study extragalactic light sources, such as quasars. Programme studies were conducted by NASA under the Explorer programme, designed to develop intermediate-size scientific experiments. NASA's Astrophysics Division will be managing the two spacecraft programmes. They are the far ultraviolet spectroscopic explorer (FUSE) and the advanced composition explorer (ACE).

FUSE will use high resolution spectroscopy at wavelengths below 1,200 angstroms to measure faint sources both throughout the Milky Way galaxy and at very large extragalactic distances. ACE will explore the energetic particle populations observed in near-Earth interplanetary space. Measurement of these particles will allow a direct study of interstellar matter. Both missions are currently under definition study and preliminary design.

B. Space physics

NASA's Space Physics Division supports investigations of the origin, evolution and interactions of space plasmas. Its studies focus on the upper atmospheres, ionospheres and magnetospheres of the Earth and other planets; the Sun as a star and as a source of solar system energy, plasma and energetic particles; the acceleration, transport and interactions of energetic particles and plasmas throughout the solar system and the galaxy.

Observations, theory, modelling, simulations, laboratory studies, interactive data analysis, instrument development and active experiments are all important aspects of the programme. Observations are made from a variety of bases including the Earth itself, high-altitude balloons, sounding rockets and satellites.

1. International solar-terrestrial physics programme

NASA will support co-ordinated international solar-terrestrial physics-related mission activity in the 1990s through the international solar-terrestrial physics (ISTP) programme. The objectives of the ISTP programme are comprehensively to measure and study phenomena associated with Sun-Earth interaction, in particular the generation of energy and plasma from the Sun and their effects on the Earth's magnetosphere, ionosphere and atmosphere. The ISTP programme comprises two major subprogrammes: the global geospace science (GGS) programme, and the ESA/NASA solar-terrestrial science programme (STSP).

Global geospace science programme

The purposes of the GGS programme are to make co-ordinated measurements of the energy flow from the Sun through four key plasma source areas of geospace and to provide the first comprehensive, multi-point studies of global magnetospheric response to the solar wind. The global energy objectives of GGS require the simultaneous acquisition of data from these key magnetospheric regions. Several missions are slated to accomplish this: Wind, manifested for launch in December of 1992; Polar, manifested for launch in June 1993; the July 1992 Japanese Institute of Space Astronautical Science/NASA Geotail mission; and the extended mission of the NASA/Department of Defense combined release and radiation effects satellite (CRRES) programme, scheduled for June of 1990.

The NASA Wind mission will provide the solar wind input function, while the NASA Polar mission will examine the deposition of the ionosphere's energy using global auroral imaging from polar orbit. The CRRES extended mission will study the acceleration of energy in the Earth's equatorial region, while Geotail, as its name implies, will measure energy flow, storage and transformation in the geotail of the Earth's magnetosphere. NASA will contribute instruments and launch the Japanese Geotail spacecraft. The entire GGS project is expected to have a total of approximately 200 investigators from many different nations. NASA will also provide tracking services for Wind, Polar and Geotail through NASA's deep space network (DSN). The Soviet Space Research Institute, in a bilateral agreement with NASA, is planning to provide co-ordinated measurements in the equatorial magnetosphere through the Regatta equator mission in 1993, which will complement the measurements provided by the CRRES extended mission.

In December of 1989, NASA and the Japanese Institute signed a memorandum of understanding on the Geotail mission. Geotail, to be built by the Japanese, will make solar-terrestrial physics measurements using Japanese and United States science instruments. As part of its dual-phase mission, Geotail will later study the equatorial magnetosphere. Geotail completed engineering model testing in 1989 and is scheduled for a flight-system critical design review in April of 1990. Also in 1989, NASA accepted a Soviet proposal to fly the gamma-ray burst instrument KONUS on the United States Wind spacecraft.

Solar-Terrestrial Science Programme

STSP is a joint endeavour by ESA and NASA to study solar, heliospheric and space plasma physics. STSP consists of two separate spacecraft investigations: SOHO and a group of four co-ordinated satellites known as Cluster. In December 1989, NASA and ESA concluded an agreement for co-operation in the joint STSP. Under this agreement, ESA will develop the spacecraft for SOHO and Cluster. NASA will launch and operate SOHO, and ESA will launch and operate Cluster. NASA will furnish an ELV launch for SOHO scheduled for March 1995. ESA will launch the Cluster spacecraft aboard an Ariane 5 ELV in December 1995.

Experiments on the spacecraft will be provided by United States and European scientists. The 18 NASA investigations for Cluster and SOHO were confirmed for flight design in 1989 and are now entering the development phase. Preliminary reviews are targeted for mid-1990.

The SOHO mission has two main purposes. One is to make long-term uninterrupted measurements of the Sun's oscillation properties, as well as measurements of its velocity and irradiance. Space physicists believe these investigations will provide important clues about the Sun's interior and internal dynamics, which in turn have important implications for the accuracy of various stellar theories. SOHO's second goal is to study the solar corona and solar abundance as an integrated system.

The Cluster spacecraft will make simultaneous scientific observations of those small-scale processes critical to understanding how the solar wind interacts with the Earth's magnetosphere. Using four spacecraft, Cluster will provide a three-dimensional study of the microphysical properties of the magnetosphere. Cluster may be enhanced by spacecraft from the planned Regatta series provided by the USSR's Institute of Space Research, which will perform complementary measurements in the polar magnetosphere.

2. Orbiting solar laboratory

The definition study on the orbiting solar laboratory (OSL) continued through 1989. The OSL spacecraft, planned for launch in 1997, will be a free-flying complement of scientific instruments in polar orbit. OSL will provide critical, high-resolution solar observations simultaneously to complement measurements from the ESA's SOHO component of ISTP, the upper atmosphere research satellite (UARS) and EOS. These observations will greatly advance mankind's understanding of the Sun and the Sun's effects on Earth.

OSL will observe the Sun almost continuously for at least nine months each year and at a reduced duty cycle during the rest of the year. This schedule allows unprecedented research on the build-up and behaviour of solar activity as well as detailed study of climactic solar events. OSL's baselined three-year flight will allow sampling the Sun from low to high levels of activity. A wide range of research programmes will be performed with OSL, including investigations by single researchers as well as major international and interobservatory campaigns. Data will be distributed rapidly to individual investigators.

OSL is designed to carry three groups of research instruments. The co-ordinated instrument package (CIP) contains a photometric filtergraph, a tunable filtergraph/magnetograph, a white-light spectrograph and a correlation tracker. The Federal Republic of Germany's BMFT is providing the white-light spectrograph. The high-resolution telescope and spectrograph (HRTS) co-observing experiment contains a Gregorian telescope, a spectrograph, a spectroheliograph and an H-alpha camera. OSL's array of instruments will enable scientists for the first time to relate phenomena on the Sun's surface with those far out in the million-degree corona, the source of the solar wind.

3. Suborbital programme

The goal of NASA's suborbital programme is to conduct research into the physical processes operating in the upper atmosphere and space through the use of balloons, sounding rockets and short-lived flights of instruments on board the shuttle.

Sounding rockets

The main objective of NASA's sounding rocket programme is to provide the means to get above the Earth's atmosphere in order to conduct astrophysics, solar physics and space physics experiments. NASA's Wallops Flight Facility at Wallops Island, Virginia, manages this programme and is responsible for an average of 40 flights a year. Several launch sites are utilized, of which White Sands, New Mexico, is the most heavily used. NASA also utilizes a number of foreign launch sites under co-operative agreements with the Governments involved. Outside the United States and Puerto Rico, NASA uses sounding-rocket launch sites in Australia, Canada, Norway, Peru and Sweden. In 1989 there were a total of 36 sounding-rocket flights.

In March 1989, NASA launched four sounding rockets from the Churchill Research Range in Manitoba, Canada. Two of these rockets released barium vapour and created greenish-purple clouds over parts of Canada and the north-central United States. The purpose of these experiments was to measure electric fields aligned parallel with the geomagnetic field. Such electric fields are thought to be important in creating the aurora. The other two flights were designed to measure physical and chemical properties of the Earth's atmosphere above 90 km altitude. Also in 1989, NASA participated together with both the Norwegian Space Centre and the Swedish Board for Space Activities in four sounding-rocket flights to study space plasma processes in the auroral ionosphere. Scientists from the United States provided a portion of the instrumentation for the payloads, while NASA provided launch vehicles and technical equipment for the flights. These sounding rockets were launched from ranges at Andoya, Norway, and Kiruna, Sweden. Scientists from all the participating countries shared in the data return.

NASA will continue its co-operation with other nations in the area of research using sounding rockets. Negotiations are under way with the Swedish and Norwegian space organizations for various research studies using sounding rockets and for launch facility arrangements. In the summer of 1991, NASA plans a campaign of seven sounding-rocket launches from Puerto Rico, near the Arecibo Radar Observatory, to conduct scientific experiments as part of the CRRES programme.

Balloon flights

In 1989, NASA continued to engage in investigational balloon flights from the Prince Albert Facility in Canada, looking primarily for chemical isotopes in cosmic-ray abundances. Low-energy cosmic rays exist in greater abundance at higher latitudes. The lower the energy level, the more particles there are and the greater their flux, which enhances the possibility of detecting isotopes. One significance of the study rests in the fact that radioactive nuclei have certain half lives from which scientists can derive the age of cosmic rays. The results

obtained so far point to a cosmic-ray age of roughly 10 million years, making them much younger than the solar system, which is thought to have formed 4 billion years ago. Supernova explosions, either directly or indirectly, have been a prime theoretical candidate for the source of cosmic rays. The Canadian balloon flights may also provide evidence of anti-matter, such as anti-protons or even anti-elements like anti-helium or anti-iron.

In the spring of 1989, NASA completed its final balloon campaign from Alice Springs, Australia, to study supernova 1987A. The campaign included four United States flights and two Italian flights. Data from these flights continue to be studied internationally.

Also in 1989, a new high-altitude scientific balloon was successfully flown from Fort Sumner, New Mexico, by the National Scientific Balloon Facility. The 40 million-cubic foot balloon carried a 5,600-pound suspended weight to an altitude of 123,000 feet. NASA also completed its first test flight in the newly established NASA-National Science Foundation programme to develop a capability for long-duration balloon flights in Antarctica. The balloon carried four independent scientific payloads on a single gondola weighing more than 3,000 pounds. The project goal is to have operational capability by December 1991, in time to support circumpolar flights for the Max '91 solar balloon programme.

Short-lived satellite shuttle flights

Short-lived satellite shuttle flights mainly revolve around the Hitchiker programme designed to permit people to build small self-contained experiments to be put up on the Shuttle. Scientists propose such investigations and then the "hitchiking" packages are chosen and flown. Most investigations essentially involve the magnetosphere and ionosphere.

4. ASTROMAG

ASTROMAG will be a superconducting magnet facility for particle astrophysics and space physics experiments requiring a large volume of high magnetic field in space. The facility will be jointly developed with the ASI and will be one of two facilities to be placed on the truss structure of the Space Station Freedom in the late 1990s. Placement of ASTROMAG on the Space Station permits an initial observing time of from two to three years, 100 times longer than is possible with balloon experiments.

In June 1989, three particle astrophysics investigations were selected for ASTROMAG. Of these three experiments, one is a co-operative project with Italy and the Federal Republic of Germany, a second is a co-operative project with Denmark and the third is a co-operative project with Japan. The science goals include investigating the origin and evolution of matter in the galaxy by direct sampling of galactic material; examining cosmological models by searching for anti-matter and evidence of the nature of dark matter; and studying the origin of extremely energetic particles and their effects on the dynamics and evolution of the galaxy.

By augmenting ASTROMAG's strong magnetic field with a variety of specialized detectors, state-of-the-art spectrometers will be employed to address the experimental objectives. Measurements of high-energy cosmic-ray nuclei and electrons will be made with precision and sensitivity 10 to 1,000 times that of previous experiments. The Space Station is an ideal spacecraft for ASTROMAG, because it provides both the assembly and servicing capabilities needed for change-out of experiments and replenishment of liquid helium to extend the life of the facility.

One instrument, Wizard, will measure the energy spectra of light particles, including antiprotons, positrons and electrons, and search for anti-helium at unprecedented levels of sensitivity. Another instrument, the large isotope spectrometer for ASTROMAG (LISA), will measure the spectra of elements and isotopes of heavy particles and search with unprecedented levels of sensitivity for their corresponding anti-particles. The spectra, composition and interaction study using a magnet-interaction calorimeter (SCIN/MAGIC) will use the ASTROMAG facility to search for a new state of matter (quark-gluon plasma) in ultra-relativistic nuclear interactions, as well as for measurements of cosmic-ray energy spectra at ultra-high energies that approach the region where dramatic changes in nuclear composition are expected.

5. PEGSAT

PEGSAT is a three-function payload instrument designed by NASA Goddard for flight aboard the Orbital Sciences, Inc. commercial air-launched vehicle, Pegasus. The launch of the payload aboard Pegasus is scheduled for April 1990. PEGSAT will (a) conduct studies of the Earth's magnetic field and ionosphere, (b) make environmental measurements (spacecraft attitude, temperature, pressure, structural loading and vibrations) of the Pegasus payload environment to help with future Pegasus programme specifications and (c) dispense a small, Navy experimental, communications relay satellite.

PEGSAT's magnetospheric and ionospheric studies revolve around a series of barium chemical release experiments. The interaction of the released chemicals with the magnetic fields and electric fields in the Earth's magnetosphere and ionosphere will be observed from a network of ground stations. The releases will be made within the first 60 to 90 days after launch over northern Canada and will be commanded from the ground.

The experiments are part of a NASA science plan to recover some of the science objectives that were lost when CRRES was reconfigured from a Shuttle launch to an Atlas/Centaur launch vehicle. CRRES is now planned for launch in June 1990. The release of PEGSAT barium chemical experiments in the summer of 1989 will not only provide CRRES scientists with significant scientific results much earlier than planned but also give them valuable experience prior to the CRRES mission.

C. Solar system exploration

The Solar System Exploration Division is responsible for the scientific exploration of the planets, their moons, comets, asteroids and the interplanetary medium.

1. Operational planetary spacecraft

Pioneer Venus Orbiter

NASA's Pioneer Venus Orbiter (PVO) entered its twelfth year in orbit around Venus in December 1989. The primary objective of the orbiter has been to study solar-wind atmospheric reactions over Venus. PVO provided the first radar survey of the cloud-shrouded planet and its data remain the most comprehensive survey to date. Data on the planet's surface and dense cloud cover continued to be collected and analysed in 1989.

Some of PVO's more important discoveries have been precise measurement of the planet's eight-month rotation; the discovery that Venus has no magnetic field; measurement of the planet's heavy cloud cover; and evidence that Venus had oceans about 3.5 to 4 billion years ago. PVO's orbit is gradually deteriorating as a result of gravity, and in August 1992, it is scheduled to enter Venus' atmosphere and burn up. Scientists are hoping to find visible evidence of lightning and other phenomena in the planet's atmosphere approximately six months before the Orbiter's entry.

Pioneer-Voyager solar-wind discoveries

Pioneer 10, the first spacecraft to leave the solar system, as well as Pioneer 11 and Voyagers 1 and 2 are now all currently speeding towards what is known as the heliopause. The heliopause is the boundary between the Sun's environment and interstellar space. Along the way, they continue to conduct solar-wind and magnetic-field studies. The solar wind is a stream of atomic particles that boils off the surface of the Sun and moves outward into space at a rate of about a million miles an hour. These particles form the Sun's tenuous atmosphere. Combined measurements from the four spacecraft, which are all travelling at different angles and distances relative to the Sun, have enabled investigators to link measured changes in the speed of the solar wind to variations in the Sun's corona and to shifts in its magnetic field.

Investigators feel confident that Pioneer 10 will eventually reach the boundary of the heliosphere, the region controlled by the Sun, and begin to make the first measurements of the gas in interstellar space. Scientists are also looking for two other things: a possible tenth planet on the fringes of the solar system (as indicated by past irregularities in the orbits of Uranus and Neptune too large to be completely due to the presence of Pluto) and for extremely long gravity waves, predicted by Einstein's general theory of relativity to be the result of cataclysmic events like the collision of galaxies or the formation of black holes. Pioneers 10 and 11 are ideally suited for such potential discoveries because they are "spin stabilized", which means they generate almost no forces of their own to

produce any changes in their straight-line flight paths. As a result, any small changes in their trajectories would indicate that external forces, such as gravity waves or a tenth planet, are acting on them. All of the probes are linked with the deep space tracking network.

Voyager 2 encounter with Neptune and interstellar mission

Planetary science spearheaded accomplishments in 1989 with Voyager 2's exploration of planet Neptune in the summer and its subsequent departure towards the boundary of the solar system. Voyager 2's Neptune encounter is its fourth and final planetary flyby in 12 years, having been launched in 1977. The Neptune encounter officially ended on 2 October 1989.

Voyager 2's close-up view of Neptune showed a bright blue, ringed planet with winds of 1,500 miles per hour and 6 previously unknown moons. The new moons occupy nearly circular and equatorial orbits around the planet. All move in prograde orbits (in the same direction the planet rotates), making the large moon Triton, which occupies a retrograde orbit, even more of an oddity in the Neptune system. Close-up pictures of Triton posed several new challenges for planetary geologists, the most interesting being how the coldest known body in the solar system could be one of the most geologically active, with four ice geysers. Coherent with standard policy, data on Voyager 2's encounter with the Neptunian system is being put into the National Space Science Data Center at the Goddard Space Center in Maryland and is being made available to the international community.

Voyager 2's working life among the planets may be at an end, but the spacecraft and its twin, Voyager 1, are expected to continue returning information about the various fields and particles they encounter while approaching and eventually crossing the boundary of our solar system. The spacecraft generators are expected to keep alive the computers, science instruments and radio transmitter for up to 25 or 30 more years. The long-lived project is being called the Voyager interstellar mission.

2. Planned future exploration

Magellan

The Magellan mission, the first planetary mission in 11 years, was launched aboard the Space Shuttle Atlantis on 4 May 1989. The Magellan launch marks the beginning of a "new golden age of space science" for a United States planetary exploration programme. By the time the five-year "golden era" concludes, NASA will have launched 37 major science missions that may radically alter mankind's view of the universe.

The Magellan spacecraft will conduct the most comprehensive observation of the surface and gravitational features of the planet Venus ever undertaken. During its 243-day (1 Venus rotation) primary mission, the spacecraft will map up to 90 per cent of the planet with high-resolution imaging radar. Such radar will reveal surface features as small as 273 to 377 yards. This performance exceeds that of all previous United States and Soviet missions to the sister planet.

A primary goal of the Magellan mission is to improve the knowledge of Venus' geologic history. The surface structure, electrical properties and processes that control them, will be analysed. Study of the volcanic and tectonic history will help to unravel the complex and interrelated processes that have led to today's surface characteristics. Magellan also seeks to increase the knowledge of the geophysics of Venus, principally the distribution and dynamics of concentrations of mass within the planet. This objective will be achieved by tracking subtle changes in the spacecraft's orbit as it circumnavigates the globe every three hours and nine minutes.

Magellan's altimetry experiment will result in elevation profiles of the surface. The radiometry experiment will utilize the large antenna to measure the thermal radiation emitted from the surface from which brightness temperatures will be derived. Gravity data, along with results from the Pioneer Venus orbiter mission, will refine the concept of Venus' gravity field. In all, Magellan will acquire more imaging data than all previous United States planetary missions combined.

Since being launched from the Shuttle in May of 1989, Magellan has been propelled onto its Venus trajectory by an inertial upper stage two-stage booster rocket. Once away from the gravitational pull of Earth, the spacecraft will cruise for 15 months (one and one half orbits of the Sun) before reaching its destination in August 1990. The orbit insertion rocket will then fire and place Magellan into a circular orbit around Venus. Scientists from Australia, France and the United Kingdom are participating as co-investigators with United States scientists on the project. In addition, three Soviet scientists are participating on the United States Magellan mission, in accordance with annex item 3 of the 1987 United States-USSR space agreement. This activity is being carried out under the United States-USSR Solar System Exploration Joint Working Group.

Galileo

The next 1989 launch in NASA's planetary exploration programme was the 18 October Shuttle launch of the Galileo spacecraft. Deployed from the space shuttle Atlantis, Galileo has since begun its round trip to Jupiter, where it will drop a probe into the Jovian atmosphere in the first direct study of the solar system's largest planet. Galileo is an international co-operative project with the Federal Republic of Germany, which provided the orbiter's retropropulsion module to perform mission manoeuvres and permit insertion of the spacecraft into Jovian orbit. There are also two German scientific experiments on Galileo, and German scientists are participating in five other experiments. United States and German scientists are joined by investigators from Canada, France, Sweden and the United Kingdom on the Galileo scientific team.

Galileo will use gravity assists from Earth and Venus to give it the energy it needs to reach the Jovian system in 1995. Upon arrival Galileo will inject an instrumented probe into Jupiter's atmosphere to measure its chemical composition and physical state for 60 minutes. The spacecraft will then go into orbit around Jupiter. The data from the probe will be relayed back to the Galileo orbiter for real-time transmission to Earth.

During its 22-month encounter with Jupiter, Galileo will investigate the structure and physical dynamics of the planet's magnetosphere and will conduct detailed studies of the entire Jovian system, including the planet, its ring and its four major moons: Io, Ganymede, Callisto and Europa. Galileo will collect data on Venus, the Earth and the Moon on its way to Jupiter, as it uses these planetary bodies for gravitational assists. Galileo will also encounter an asteroid in the main asteroid belt on the way to Jupiter. This will be the first close-up look at an asteroid.

Mars observer

The Mars observer mission, currently being developed for a September 1992 launch aboard a Titan-3 ELV, will place a single spacecraft in a near-polar orbit around Mars to carry out the first long-term United States study of Mars as a planet. In 1989, critical design reviews for the spacecraft, its subsystems and its flight instruments were completed. Assembly of the spacecraft will begin in May 1990.

Instruments in the spacecraft will map and study the entire surface and atmosphere of Mars for a full Martian year (687 Earth days). These observations will determine the planet's global chemical and mineral surface composition and will provide a thorough exploration of Mars' gravitational field, topography and magnetic field. Of particular interest to scientists is finding out more about the Martian climate. To that end, the Mars Observer will also study the circulation of Mars' atmosphere and will determine the distribution, abundance, and sources of dust and volatile materials over a complete seasonal cycle. The Mars Observer will begin its two-year mapping mission in late 1993 after being inserted into a 378-kilometre near-polar orbit.

Scientists from Austria, France, the Federal Republic of Germany, the Soviet Union and the United Kingdom are participating in the NASA project. Both France and the United Kingdom are providing hardware components for instruments for the Mars Observer payload. Further, the Mars Observer is being designed to conduct a Mars Balloon Relay experiment in co-operation with the Soviet Union and France. The Mars Balloon Relay antenna system will relay data and increase the yield of high-resolution imagery obtained from balloons to be deployed on Mars by the USSR Mars-94 mission, whose two spacecraft will arrive at Mars in late 1995.

Ulysses

The Ulysses mission, formerly known as the International Solar Polar Mission (ISPM), is designed to investigate the properties of the heliosphere as a function of solar latitude. The joint NASA-ESA mission is scheduled for a five-year duration with an October 1990 United States Shuttle launch of the spacecraft. Soon after the originally scheduled 1986 launch was postponed, the spacecraft was placed in storage at an ESA facility. In 1989, spacecraft testing resumed and a series of integration and environmental tests were completed to certify the craft's readiness for flight. The spacecraft's science instruments have also been retested, calibrated and recertified.

Ulysses will be launched on a trajectory to intercept Jupiter in February 1992 where it will use the massive Jovian gravity to leave the plane of the ecliptic and be deflected towards the Sun's south pole. Ulysses will overfly the high southern solar latitudes in mid-1994 and the northern latitudes in mid-1995. The mission will be completed in late 1995. ESA will provide the spacecraft, its member States will provide five of nine instruments, and ESA will integrate the instruments. The United States will provide the launch vehicle, radio-isotope thermonuclear generator (RTG) power source, four science instruments and mission operations facilities.

Lunar observer

In response to the July 1989 announcement of President Bush's Space Exploration Initiative to extend human exploration beyond Earth's orbit by first establishing a manned lunar outpost, NASA conducted a three-month study and provided a report to the National Space Council. In this report, the lunar observer mission, which involves a global scientific mapping of the Moon from lunar orbit, was identified as the first robotic component of the Space Exploration Initiative. In 1989, the lunar observer programme entered into definition study.

The objective of the lunar observer is to carry out a long-term orbital survey of the global characteristics of the Moon, including surface chemistry and mineralogy, surface geology and land forms, topography, gravity and magnetic fields. It will also obtain high-resolution imagery of surface features and search for frozen volatiles in permanently shadowed polar regions. The mission data will provide a global scientific context for more localized data obtained by the Apollo programme (including lunar sample analysis) and will also contribute to answering major questions about the global character, internal structure, origin and evolution of the Moon. The mission, especially the search for frozen volatiles, will also make major contributions to the global scientific data base needed to support future human exploration of the Moon.

The mission is currently planned to consist of a single planetary observer spacecraft launched from Earth by an ELV and placed into a 100-km circular near-polar orbit. The nominal mapping mission will last two years, permitting extensive and overlapping lunar coverage, especially near the polar regions. A launch date of late 1996 is anticipated for the observer.

3. Comet rendezvous asteroid flyby/Cassini programme

Two missions, the comet rendezvous asteroid flyby (CRAF) and Cassini (the Saturn Orbiter/Titan probe), combine to form the CRAF/Cassini programme, the first in a series of planetary missions whose common objective is to explore primitive bodies and the outer solar system, towards the ultimate goal of understanding the origin of our solar system and of life itself. To obtain the data needed to address that goal, the CRAF and Cassini missions carry different scientific instruments on spacecraft of the same basic design. This versatile spacecraft, called the Mariner Mark II, is currently under development.

Comet rendezvous asteroid flyby

The first mission to use the Mariner Mark II is CRAF, a co-operative mission between NASA and the Federal Republic of Germany. CRAF has two main objectives: a close flyby of at least one large asteroid located in the asteroid belt between the orbits of Mars and Jupiter, and a multi-year rendezvous with the short-period comet, Kopff. Both the asteroid and the comet exploration have the same purpose - to enhance human understanding of the evolution of the solar system and perhaps of the origins of life on Earth.

Comets and asteroids are the most primitive bodies in the solar system. Scientists hypothesize that the planets were formed through the accretion of countless small bodies called planetesimals that were similar to asteroids and comets. It is believed that the asteroid belt was kept from forming a planet by disturbances caused by Jupiter's gravity and asteroids therefore may have retained primitive chemical and physical properties similar to the planetesimals thought to have formed the inner terrestrial planets. CRAF will characterize the physical and geological structure of an asteroid and the distribution of minerals on its surface.

Just as asteroids may be fragments similar to the building blocks of the rocky inner planets, comets may be the icy remnants of the accretion of the outer planets. Exobiologists are also intrigued because comets could be the key to explaining how the essential ingredients needed for the formation of organic life first appeared on Earth. CRAF will fly in formation with a comet for three years as it moves around the Sun from its farthest to its closest distance. Imaging at a resolution of better than one metre, CRAF will relay information about the size, shape and surface structure of the comet's nucleus to discover how it accreted. A penetrator will be fired directly into the comet's nucleus to measure its elemental composition. As the comet nears the Sun, CRAF will weave in and out of the expanding cometary atmosphere and will measure the chemical properties, temperature and velocity of the gases and dust in the comet's tail. These measurements should tell researchers if the light elements on Earth are of the same isotopic composition as those found on the comet.

The co-operation between NASA and the Federal Republic of Germany will follow closely that already established for the Galileo mission. The Federal Republic of Germany will provide portions of the propulsion module subsystem in exchange for participation in the scientific payload. The Federal Republic of Germany has conducted definition studies of the propulsion system and has participated on the science team defining the mission. The Federal Republic of Germany, as well as other foreign co-investigators involved in the mission, will provide instrumentation and components for the CRAF payload. Co-investigators on the project come primarily from the Federal Republic of Germany but also from Austria, France, Italy, Japan, the Netherlands and the United Kingdom. CRAF is still under design definition for the instrumentation and spacecraft subsystems and is scheduled for an August 1995 launch aboard a Titan IV rocket.

Cassini

Cassini will be the second mission to utilize the Mariner Mark II spacecraft. Cassini is a joint endeavour with ESA. Named for the Italian/French astronomer who

discovered four of Saturn's moons, Cassini will conduct a comprehensive scientific investigation of the Saturnian system, including the planet's rings and moons, and the fields and particles in its magnetosphere. An ESA-provided probe, named Huygens, will make in situ measurements of the atmosphere of Titan, Saturn's largest moon, and the Saturn Orbiter will make close flybys of a number of the planet's other satellites.

Saturn's system of rings and icy satellites is so complex that it is often compared to a miniature solar system. Researchers feel that understanding the overall dynamics of the Saturnian system is relevant to understanding the interaction of dust, gas and planetesimals in the primordial solar nebula from which the solar system itself was created. Also, unique properties of the Saturn system, such as the presence of methane in Titan's atmosphere, along with evidence of complex organic chemistry (possibly including a methane ocean and methane rainfall) and observations of a dark hemisphere on another moon, Iapetus, that scientists feel could be organic in nature, have heightened interest in the Saturnian system as one location in which early biological evolution might be occurring. Cassini will build on the Galileo and CRAF missions by flying by at least one asteroid and Jupiter en route to Saturn. A comparison of data from Galileo and Cassini will also be conducted to determine similarities and differences between the Jovian and Saturnian systems.

ESA approved its participation in Cassini in November 1988 and Congress approved NASA's participation in the summer of 1989. Announcements of opportunity, soliciting instrument proposals for the Huygens probe and Saturn orbiter were issued by ESA and NASA, respectively, in October 1989. Cassini is scheduled for launch in April 1996 aboard a Titan IV ELV, arriving at Saturn in late 2002.

4. 1989 asteroid flybys

In the spring of 1989, NASA scientists discovered that on 23 March an asteroid a half-mile (0.83 km) or more in diameter passed within 500,000 miles (830,000 km approximately) of the Earth, about twice the distance between the Earth and the Moon. Further, in the fall, scientists at the Arecibo Observatory in Puerto Rico used the radio telescope there to map another asteroid that passed within 2.5 million miles (4.15 million km) of the Earth. Relayed images showed a two-lobed body a mile (1.7 km) long spinning like a propeller every four hours.

D. Earth sciences and applications

The goal of the Earth Sciences and Applications Division is to observe the Earth and predict changes that are likely to take place within it, on its surface and in its atmosphere, whether those changes are naturally occurring or are induced by human activity.

1. Atmospheric research

Airborne Arctic ozone experiments

Results from the 1987 Antarctic Ozone Campaign and study of the Antarctic ozone hole led to profound changes in thinking about stratospheric chemistry and dynamics in the polar regions and increased speculation that similar phenomena might be occurring to a lesser, but important, extent at northern high latitudes. Hence, in 1989, the Arctic Ozone Campaign was undertaken to examine the chemical and dynamical processes that control ozone in the Arctic winter stratosphere. The overall goal of the mission was to establish whether the processes that contribute to Antarctic ozone depletion are operative in the northern hemisphere.

The airborne Arctic stratospheric expedition was similar to the Antarctic campaign except that it was performed in the middle of winter rather than in late winter/early spring. The campaign utilized two aircraft, a high-altitude ER-2 and a modified DC-8 based at Sola Airfield near Stavanger, Norway, (59° N, 6° E) from 1 January to 15 February 1989. These aircraft were equipped with state-of-the-art instrumentation (13 instruments on the ER-2 and 10 on the DC-8) for determining the chemical composition and physical state of the atmosphere. Satellite and ground-based measurements were also vital and integral components of the campaign. Teams of theorists participated with the experimentalists in flight planning and in the interpretation of the data. There were 14 flights of the DC-8 and 14 of the ER-2. DC-8 flights went as far north as the Pole and as far west as the western coast of Greenland. The ER-2 ranged as far as 82° N and the centre of Greenland.

The key findings of the 1989 airborne Arctic stratospheric expedition were that the chemical composition of the Arctic polar stratosphere was found to be highly perturbed. Measurements of several chemical compounds and ozone-depleting substances indicated that perturbations occurred over a wide range of altitudes in the stratosphere in the Arctic region. The observations added up to a consistent picture that is similar to the one drawn from the Antarctic data in 1987 and are believed to be the result of chemical reactions occurring on polar stratospheric clouds that form at the cold temperatures in the polar regions. Nevertheless, in the Arctic campaign, scientists could find no unequivocal signature of a photochemical loss of Arctic ozone before the end of the mission.

In addition to NASA and NOAA scientists, managers, aircraft pilots and crew, scientists and technicians from the National Science Foundation's National Center for Atmospheric Research, the United Kingdom Meteorological Office, the United Kingdom Department of Environment, the University of Oslo and the Norwegian Meteorological Office participated in the project. Additional data were supplied by the Federal Republic of Germany, Danish and Soviet balloon-sounding teams located throughout the Arctic region.

Nimbus-7 total ozone mapping spectrometer

The total ozone mapping spectrometer (TOMS) instrument aboard NASA's Nimbus-7 satellite has been measuring stratospheric ozone for more than 10 years as a part of the earth science programme managed by NASA. To support Antarctic scientists in their ozone campaign Goddard Space Flight Center has been processing the data from

TOMS in near real-time and observations are transmitted to researchers around the world. In 1989, continuing observations by TOMS have gathered further evidence of humans' effect on their environment as data showed the ozone levels over Antarctica between August and October were as low in 1989 as the record low levels measured in 1987. Earlier aircraft campaigns had already shown that the ozone hole over Antarctica was caused by human activities, specifically the release of chlorine compounds.

The TOMS sensor on Nimbus-7 has provided a continuous global record of ozone over the full depth of the atmosphere since 1978, but the instrument is now reaching the end of its useful life as Nimbus-7's operational lifetime comes to a close. To continue these measurements, NASA has made arrangements for a TOMS instrument to fly on a Soviet Meteor-3 satellite and on the Japanese advanced earth observation satellite; a low-cost United States satellite to carry a TOMS payload is also being designed. Thereafter, instruments to monitor ozone will be carried on future NOAA satellites.

Global tropospheric experiment

The global tropospheric experiment (GTE) is actually a series of experiments. It has two main goals related to tropospheric chemistry. One is to conduct a series of field measurements to determine the susceptibility of the Earth's atmosphere to chemical change. Collectively these field expeditions are referred to as the atmospheric boundary layer experiments (ABLE). The second goal is to evaluate the performance of instruments being developed to measure various trace elements in the atmosphere, through a programme called chemical instrumentation test and evaluation (CITE).

The impetus for GTE came in 1981 when the measurement of air pollution from satellites (MAPS) instrument on the Space Shuttle found heightened carbon monoxide levels in several areas of the globe. This prompted an urgent and concentrated effort to discover more about the role of discrete groups of gases that compose less than 1 per cent of the volume of the atmosphere but could, when interacting with infrared radiation, produce the global warming scenario known as the greenhouse effect, as well as other forms of climatic change.

Researchers from NASA, NOAA, and the National Science Foundation, selected several ecosystems for field studies that are particularly important as atmospheric change agents. Field study areas included the tropical Atlantic, the Amazone rain forests of Brazil (which constitute one of the world's most important ecosystems because they are the most efficient "sink" of ozone yet discovered), the Arctic tundra and subarctic peatlands (conducted from Alaska) and the Canadian wetlands. All of the GTE-ABLE investigations used a combination of aircraft, ground-based, and satellite monitoring.

In 1989, NASA scientists analysed data from the GTE/ABLE-3A campaign that took place in the Alaskan tundra in 1988. They also continued planning for the GTE/ABLE-3B campaign to take place in the Canadian wetlands in the summer of 1990. Researchers further prepared papers for publication of GTE/ABLE-2B (Amazon rain forest) data. In September, the third GTE/CITE experiment was conducted out of

Natal, Brazil. Natal was selected for its clean oceanic air conditions. The GTE/CITE-3 campaign focused on studying the performance of various sulphur instruments in the atmosphere.

In the 1990s, a series of aircraft missions called GTE/Pacific exploratory missions (PEM) will focus on making measurements of concentration distributions of atmospheric trace gases important to the greenhouse effect. There will be four PEM experiments beginning in the fall of 1991. GTE/PEM was adopted as part of the International Global Atmospheric Chemistry Programme, as part of the East Asia/North Pacific regional programme of the international geosphere-biosphere programme (IGBP).

In 1992, the GTE/Transport and Chemistry near the Equator - Atlantic (TRACE-A) campaign will be initiated. GTE/TRACE-A will study the impact of biomass burning in Brazil and Africa on tropospheric ozone over the South Atlantic. Non-United States investigators can propose experiments for participation in both PEM and TRACE-A.

Earth radiation budget experiment

The disputed effects of clouds on the Earth's temperature has been resolved by NASA's earth radiation budget experiment (ERBE) satellite. Prior to the ERBE measurements, scientists were undecided as to whether clouds trapped more heat than they reflected. They were therefore unable to assess the role that clouds play in today's climate, let alone to predict their effect on changes in climate due to the greenhouse effect. ERBE findings should significantly improve the accuracy of current climate models.

ERBE is made up of instruments carried by three satellites, ERBS, NOAA-9, and NOAA-10. Data obtained from these satellites show that the effect that clouds have on the Earth's climate depends on the type of cloud and its altitude. Thin cirrus clouds tend to warm the surface of the Earth because they are transparent to incoming solar radiation, yet are efficient at trapping infrared heat emitted from the Earth. Low-level stratocumulus clouds, however, are highly reflective of the solar radiation but emit almost as much infrared radiation back into space as the Earth's surface does. Therefore, clouds act somewhat like venetian blinds with respect to the global heat budget. Whether or not the greenhouse effect can be expected to predominate over the albedo effect depends in part on how the relative abundance of various clouds in certain areas is expected to change.

This ERBE data base will be complemented by the International Satellite Cloud Climatology Project (ISCCP), a joint programme of the World Meteorological Organization (WMO) and the International Council of Scientific Unions (ICSU), to create a data set from which to infer the global distribution of cloud radiation properties. NASA is responsible for processing and combining the data from meteorological satellites operated by the United States, ESA and Japan.

Global Surface Radiation Budget Experiment

In 1989, NASA conducted the first global surface radiation budget (SRB) satellite data validation experiment to measure solar and thermal radiation reaching the ocean and land surfaces under all types of clouds. The purpose of the experiment, which is part of the World Climate Research Programme, was to obtain a special set of high-quality data from a number of ground-based verification sites, known as ground truth sites, during April. Each of these sites made local mesurements from horizon to horizon.

Since approximately 70 per cent of the globe is ocean, it was essential that ground-truth data at several ocean sites be obtained. These measurements were collected by NASA, NOAA, the United States Army, the Canadian Atmospheric Environmental Service and environmental agencies in Italy, Australia and Switzerland. NASA Bermuda stations took solar and thermal data as did NOAA stations in Kwajalein Island and American Samoa. Switzerland collected mountain data; the South Pole, Antarctic coast, Alaska and Northern Canada sites collected polar data; White Sands, New Mexico, collcted desert measurements; Boulder, Colorado, collected high plains data; and other parts of Canada collected variable-latitude data.

Regional validation studies will be conducted for each of the surface data sets around the globe. The ultimate goal of the experiment is to publish global maps showing the balance of the surface radiation energy coming from the Sun and emitted from the Earth.

Upper atmosphere research satellite

The Earth's upper atmosphere is thin, fragile and almost invisible, yet it plays a fundamental role in global climate and provides a shield against harmful ultra-violet radiation from the Sun. Studies have shown, however, that this shield - the stratospheric ozone layer - may be failing. NASA's UARS is part of the scientific response to this concern.

UARS is the spearhead of a long-term, international programme of space research into global atmospheric change. Under United States leadership, the UARS programme will carry out the first systematic detailed satellite study of the Earth's stratosphere, mesosphere and lower thermosphere and establish the comprehensive data base needed for an understanding of stratospheric ozone depletion. Scheduled for deployment by the Space Shuttle in late 1991, the UARS mission will also lay the foundations for a broader study of upper-atmosphere influence on climate and climatic variations.

An important aspect of the UARS programme is its co-ordination with additional national and international programmes of study and data acquisition. Other nations are contributing UARS instruments and scientists from many nations will ultimately participate in the analysis and utilization of UARS data. Upon completion of the UARS mission, the international scientific community will have gained a dramatically expanded and detailed picture of the energetics, dynamics and chemistry of the upper atmosphere. This information will then be available to

Governments around the world, enabling them to address more effectively the role of human activities in altering upper-atmosphere properties.

NOAA satellite-11

NOAA-11 began its first full year of operation in 1989 and it joins NOAA-9 and NOAA-10 in collecting meteorological and ocean data on an operational basis for direct transfer to users around the world. NOAA-11 is part of the United States civil operational environmental satellite programme operated by NOAA. NASA is responsible for the design, engineering, procurement and launch of the NOAA Sun-synchronous polar orbiting series of satellites and of the geostationary operational environmental satellites (GOES). NOAA funds the development, launch and operation of the satellites and is in charge of the satellites once they are operational. In addition to weather forecasting the NOAA satellites are used for hurricane warning and tracking; monitoring global sea ice; providing information on ozone depletion; solar measurements; and agricultural, fishing, forestry, maritime and industrial use.

Among the seven instruments carried by the new NOAA-11 satellite are instrumentation of the satellite-aided search and rescue programme (SARSAT) operated by the United States, the Union of Soviet Socialist Republics, France and Canada. Similar instrumentation is already present on NOAA-9 and NOAA-10 and on two Soviet satellites. The satellites are able to relay distress signals from ships or downed aircraft to help recovery forces locate the distressed vessels more quickly. A second instrument, the solar backscatter ultraviolet spectral radiometer, Mod 2 (SBUV-2), is an improved instrument for measuring solar irradiance and the ozone concentration and distribution in the Earth's atmosphere. NOAA-11's instrumentation to measure temperatures throughout the Earth's atmosphere includes the high-resolution infrared sounder (HIRS); the stratospheric sounding unit (SSU), provided by the United Kingdom; and the microwave sounding unit (MSU). Global day and night imagery in five spectral bands is gathered by the advanced very high-resolution radiometer (AVHRR). A French instrument, the ARGOS data collection system (DCS), receives pressure, temperature and altitude data from about 2,000 buoys, balloons and remote weather stations world wide and provides position location.

2. Oceanic processes

TOPEX/Poseidon

In order to understand fully the role of the oceans in carbon dioxide intake and in global heat redistribution, which in turn have important implications for predicting climatic changes attributable to the greenhouse effect, both ocean temperatures and ocean currents must be measured. The ocean topography experiment (TOPEX)/Poseidon, a joint programme of NASA and the French National Centre for Space Studies, addresses one aspect, the measurement of currents, by using a satellite equipped with precision altimeters to map ocean topography with an accuracy on the order of 15 centimeters (six inches). Ocean surface topography is associated with ocean circulation caused by currents such as the Gulf Stream that

flows past the North American east coast and across the North Atlantic to warm much of northern Europe. Other scientific objectives of TOPEX/Poseidon address ocean tides, ocean heat transport, statistics of ocean variability, the marine geoid and geophysical studies of lithospheric and mantle processes.

TOPEX/Poseidon is a truly international co-operative effort. In addition to the Ariane 4 launch vehicle, France will provide an experimental single-frequency solid-state altimeter and a radiometric Doppler tracking system called DORIS. NASA will provide the spacecraft and instrument integration, an advanced dual-frequency altimeter, microwave radiometer, retroreflectors for ground-based laser tracking and an experimental global positioning system tracking receiver. NASA and the French Centre have selected an international team of scientists comprising 38 investigations, and representing Australia, the Federal Republic of Germany, France, the United Kingdom, Japan, the Netherlands, Norway, South Africa and the United States.

TOPEX/Poseidon is also a vital contributor to major international ocean/atmosphere research programmes. The TOPEX/Poseidon data set will serve as the centerpiece of the world ocean circulation experiment (WOCE), an international project that is a component of the World Climate Research Programme. WOCE will result in the first comprehensive study of the physical properties of the oceans and will contribute to successful prediction of global climatic change on the scale of decades. TOPEX/Poseidon will also contribute to the tropical ocean global atmosphere (TOGA) programme. The present launch schedule of June 1992 will place TOPEX/Poseidon in orbit to allow a three-year overlap with WOCE and TOGA. Because WOCE and TOGA are primarily field programmes, the holistic value of combining them with TOPEX/Poseidon greatly enhances the benefit of the ground-based and satellite measurements considered separtely.

NASA scatterometer/advanced earth observing satellite

A long recognized limitation of the international scientific community's ability accurately to model and understand both the oceanic and atmospheric circulations is the lack of systematic measurements of the global marine wind fields. The NASA Scatterometer (NSCAT) is a satellite radar designed to measure wind speed and direction over more than 90 per cent of the ocean every two days. A scatterometer measures the return power of radar energy scattered by small ripples on the sea surface. This measurement is affected by the wind speed, the angle of the wind to the radar beam and the angle of the radar beam to the vertical. The NSCAT mission will provide requisite data for the wind forcing of ocean models and surface data input to atmospheric circulation models. Ultimately, observational analyses and modelling studies applying NSCAT data will yield a better understanding of the coupled ocean/atmospheric circulations and climate.

NSCAT was originally proposed as a NASA instrument to fly on a United States satellite. However, owing to changes in the satellite programme, NASA proposed that NSCAT fly as a payload aboard the Japanese advanced earth observing satellite (ADEOS). In 1989, after accommodation studies, the Japanese NASDA formally approved NSCAT for flight on ADEOS. A launch date for ADEOS is planned for 1995.

NSCAT has developed into an international co-operative effort as a result of the new relationship with Japan and ADEOS. NASA will provide the scatterometer and Japan will provide the spacecraft and launch. Like TOPEX/Poseidon, NSCAT can also provide data for WOCE and TOGA programmes. The present launch schedule could place NSCAT in orbit in the late phases of WOCE and TOGA and will provide overlap with follow-on programmes. In addition to vastly improving understanding of wind stress over the ocean, NSCAT data assimilated into atmospheric models should significantly improve their forecasting reliability. To this end, NASA and NASDA are considering mechanisms to make NSCAT data available quickly to operational forecast centres.

Coastal zone colour scanner archive

Knowledge of the amount and distribution of phytoplankton, the microscopic plants that grow in the upper, sunlit regions of the oceans, is crucial to a better understanding of the marine food web and the role of the oceans in the global carbon cycle, since the carbon fixation through photosynthesis occurs at roughly the same rate in the oceans as it does on land. The inability of researchers in ships adequately to sample the vast ocean hampered the effort to obtain the needed data until NASA scientists decided to take advantage of the fact that chlorophyll and other pigments in phytoplankton absorb light during photosynthesis. NASA developed the coastal zone colour scanner (CZCS) that was launched on the Nimbus-7 satellite to measure the change in the ratio of green to blue light (chlorophyll pigments absorb blue light, making the oceans appear more green) and thus calculate the oceanic chlorophyll concentration. During its seven and a half year lifetime, from 1978 to 1986, CZCS acquired nearly 66,000 images, each covering up to 2 million km^2 of ocean surface, and is the most comprehensive source of ocean colour measurements to date.

NASA has reprocessed and archived the CZCS data. The result is a global ocean chlorophyll data set that is available for the use of the international oceanographic community to help to determine the dependence of year-to-year variability of fish stocks on phytoplankton productivity, as well as the role of the oceans as a carbon dioxide sink with its associated implications for greenhouse warming. The archiving system takes advantage of technological improvements in digital optical disc storage. All data have been distributed on optical discs to a number of university sites and are available to the international community through the Goddard Space Flight Center. NASA is currently exploring options for a follow-on ocean colour sensor to bridge the period from CZCS to the moderate-resolution imaging spectrometer (MODIS) that will be part of EOS, which is expected to be operational by the end of the 1990s.

Alaska synthetic aperture radar facility

In 1989, NASA continued installation of a synthetic aperture radar (SAR) receiving station that will be located at the University of Alaska at Fairbanks. The Alaska SAR Facility (ASF) is a collaborative project between NASA and a number of other national and international scientific and technical agencies and organizations. The ASF 10-metre antenna will be able to receive signals from three satellites, European, Japanese and Canadian, carrying SAR devices capable of penetrating clouds and darkness, traditional high-latitude limiting factors, to

produce images of the ice, land and seas in and around Alaska, western Canada, and eastern Siberia in the USSR. SAR demonstrates a remarkable ability to obtain all-weather imagery of the Earth's surface.

The facility is scheduled to be fully operational in time for the 1991 launch of ESA's first remote-sensing satellite (E-ERS-1), which will carry a C-band frequency SAR primarily to produce high-resolution maps of the Arctic oceans and ice pack. ASF will receive and process data from the ESA E-ERS-1 satellite as well as from the Japanese J-ERS-1 earth resources satellite, which includes an L-band SAR that will focus mainly on land-based applications. J-ERS-1 is scheduled for a 1992 launch. RADARSAT, carrying a Canadian-led multinational C-band SAR for ocean and sea ice monitoring, will become the third satellite to provide direct data to ASF. In 1989, the Canadian Government approved RADARSAT, and NASA agreed to provide its launch.

Among the results that scientists hope to obtain from the SAR data is a description of the Arctic ice pack in terms of its ice type, flow size, open water distribution, and the motion of the ice. Understanding the polar oceans and ice pack is important because the temperature differential between the cold polar atmosphere and the warmer oceans makes the Arctic a site of great heat loss, with significant impact on the global climate system. Land-based SAR applications for the ASF region include measurements of changes in Alaskan glaciers, investigation of the tectonics of northern mountain ranges and measuring the possible effects of climatic stresses on vegetation due to acid rain or to greenhouse warming of tundra and boreal forests.

The location of ASF will complement other SAR receiving facilities that will be located under ESA direction in Canada, Norway, Sweden and the United Kingdom. Together, these stations will provide SAR coverage of nearly all northern mid- and high-latitude regions. A further complement will be provided through a major research project called the programme for international polar ocean research (PIPOR). PIPOR will apply ERS-1 SAR data to ocean and ice research problems. This project involves more than 100 investigators from North America, Europe, Japan and Australia.

3. Land processes

The land processes programme consists of three interrelated elements: studies of terrestrial ecosystems, hydrology and remote-sensing science. The focus of land processes is on the conduct of research in the Earth sciences using currently available systems and airborne prototypes for future systems with some attention given to the development of new instruments and techniques for future scientific and applied use.

International satellite land surface climatology study

The international satellite land surface climatology project (ISLCP) was initiated with the support of the United Nations Environment Programme (UNEP) to address methods for improving satellite sensing over the Earth's land surface. The

major land processes field experiment activity in 1989 was an extension of the successful 1987 activity in Kansas known as the first international satellite land surface climatology project field experiment (FIFE). Over 150 international investigators in 30 teams occupied the Konza Prairie near Manhattan, Kansas, for 21 days in August 1989. Supported by six aircraft bearing state-of-the-art remote-sensing systems and data from Landsat, France's Systeme probatoire pour l'observation de la Terre (SPOT), NOAA-10 and -11 and GOES satellites, the team studied the late summer dry-down of the prairie vegetation. At this time the control of the flux of water vapour from the soils and vegetation into the atmosphere shifts from predominantly biological mechanisms to predominantly physical mechanisms. The study was designed to relate remote-sensing measurements to biological productivity and evapotranspiration, laying the groundwork for future climatic and ecological studies including problems of global warming and desertification.

The 1989 extension of the 1987 experiment was needed in order for the science teams to study the desired seasonal change and the associated biological phenomena that they were unable to study owing to weather conditions in 1987. FIFE-89 also provided an opportunity to enlarge the international participation of the experiment to include nine investigators from the Soviet Union as well as investigators and instrumentation from Canada, France and the United Kingdom. The Soviet team brought instruments which they had used in similar experiments, including one which had flown on their Mir space station.

Boreal forest field study

Building upon the understanding and scientific expertise developed during FIFE, NASA is currently planning a major boreal forest field study. The preliminary experiment plan, published in April 1989, calls for surface, airborne and satellite observations to investigate interactions between the boreal forest biome and the atmosphere in order to clarify their roles in global change. The boreal forest study will combine elements of terrestrial ecology, land surface climatology and tropospheric chemistry to understand the major exchanges of radiation, heat and trace gases. Two planning workshops were held in 1989. Collaboration with Canada has been discussed, and a joint United States-Canada Science Steering Committee has been formed to further the scientific planning for 1993-1994 field campaigns.

Advanced sensor development

Advanced airborne sensors that are prototypes for EOS instruments continue to play an important role in the land processes studies. Highlights in 1989 included numerous flights by the airborne visible infrared imaging spectrometer (AVIRIS) and the airborne SAR in support of scientific investigations. AVIRIS is the prototype for the EOS high-resolution imaging spectrometer (HIRIS), and SAR is the prototype for the planned EOS SAR. Additionally, the advanced solid-state array spectroradiometer (ASAS), a prototype for the moderate resolution imaging spectrometer (MODIS) was used in initial tests for geological investigations and the thermal infrared multispectral scanner (TIMS) was refurbished after approximately eight years of service. The electronically steerable thinned

aperture radiometer (ESTAR), a system for remote measurement of soil moisture, moved closer to operations, with a successful calibration programme and additional test flights over known targets.

Terrestrial ecosystem studies

Results of a three-year ecosystem modelling study to estimate annual evapotranspiration and net photosynthesis for a large region in the state of Montana were published in 1989. A simple geographic information system was used to integrate topography, soils, vegetation, and climatic data. NOAA AVHRR data were used to estimate leaf area index, an input for the model. The modelled results for evapotranspiration and photosynthesis across the landscape followed expected trends in both magnitude and spatial pattern. This research will continue with a goal of scaling up to the even larger spatial scales of general circulation models so that realistic, mechanistic ecosystem process understanding can be incorporated into global climate prediction models.

NOAA AVHRR data are also being used to study deforestation in the Amazon basin as well as, more recently, in tropical forest regions of Africa and Asia. The goal is to generate coarse resolution, global-scale estimates of tropical deforestation. AVHRR thermal data are further being used better to understand the role of fire in the deforestation process and to assess its effect on the atmosphere.

Also in 1989, an important research paper was published describing a collaborative effort between United States and Brazilian scientists to study a simulated destruction of the amazon rain forest using a global climate model. The model used included an explicit biosphere and called for continual replacement of the destroyed rain forest with grassland. The result of the experiment was a permanent alteration of rainfall patterns in Brazil, but it also showed important effects on global rainfall and temperature patterns.

4. Geodynamics

Laser geodynamics satellite-2

A second laser geodynamics satellite, LAGEOS-2, is being developed under a joint agreement between NASA and the Italian Space Agency. Like its predecessor, LAGEOS-1, that was launched by NASA in 1976, LAGEOS-2 will be a small spherical satellite studded with 426 retroreflectors. Its orbit will be so stable that its position at any given moment can be determined with a high degree of accuracy. Its spherical shape and retroreflectors are designed to reflect back laser beams aimed at the satellite from world-wide ground stations, including one in Matera, Italy. Any shift in the position of the Earth's crust greater than two centimetres can be detected by changes in the round trip travel time of the laser beams. Such information is extremely important for monitoring fault movements in regions of the world that are prone to earthquakes.

LAGEOS-2 will have the same circular orbit as LAGEOS-1, but its angle of orientation will be different (52° inclination instead of 110°). By tracking both

of the satellites, the accuracy of the data obtained is expected to improve by a factor of two. It may permit researchers to measure the Earth's rotation rate, the ocean's tidal dissipation and the rate of separation between the Earth and the Moon. LAGEOS-1 and -2 are precursors to the EOS geoscience laser ranging system (GLRS), which reverses the standard approach of laser ranging by putting the laser source in orbit and the retroreflectors on the ground.

Italy is responsible for fabrication of LAGEOS-2 and for its integration with a spinning upper stage known as the Italian research interim stage (IRIS) that can be used to deploy light-weight satellites from the Space Shuttle. The United States will furnish existing ground support equipment, conduct optical tests of the satellite and launch the satellite from the Shuttle. This co-operation between NASA and ASI builds on a long history of co-ordinated effort in the area of geodynamics. In 1989, an international team of 27 investigators was selected representing the following six countries: United States, Italy, Federal Republic of Germany, France, Netherlands and Hungary. Also in 1989, the laser/optical testing of the spacecraft was completed, and the craft was delivered to the Goddard Space Flight Center. Lageos-2 is scheduled for launch in December 1991.

5. Mission to planet Earth - the Earth observing system

To understand global change and the increasing demands of human activity, it is essential to document and comprehend how the Earth works as a system. The international scientific community is organizing research efforts to advance knowledge of both natural and human-induced global change. The United States global change research programme, a consensus inter-agency plan, defines the United States element of those efforts. Mission to planet Earth, the central NASA contribution to the United States global change research programme, includes two proposed initiatives: EOS and Earth probes, as well as a series of geo-platforms to be proposed in the future.

EOS consists of a space-based observing system, a data and information system (EOSDIS), and a scientific research programme. It represents the initiation of a comprehensive, global observing system with broad and high-resolution spectral and spatial, as well as long-term temporal, coverage of the Earth. The space component will consist of two series of polar-orbiting platforms, with the launch of the first platform in 1997. EOS will be supplemented by companion European and Japanese platforms, as well as the continuing operational environmental satellites.

EOS will continue and integrate the measurements now being taken by short-term research missions. It will provide the first co-ordinated simultaneous measurements of the interactions of the atmosphere, oceans, solid Earth and hydrologic and biogeochemical cycles. Earth probes will provide a focus on observing specific Earth processes where smaller platforms and/or different orbits from EOS are required. In addition to complementing EOS, Earth probes will provide critical near-term observations.

As the corner-stone of the Mission to planet Earth, EOS will be one of the largest science missions ever undertaken, providing 15 years of comprehensive data

on Earth's atmosphere, oceans and land. It will help the international scientific community to understand the complex interactions of the environment, to assess humanity's role in shaping them and to build credible models capable of predicting future change. In 1989, a group of 41 instruments from the United States, Canada, Japan and Europe was selected for flight on EOS, and over 500 scientists from 13 countries were identified to participate in the EOS programme.

E. Life sciences

The NASA life sciences programme is planned and directed by the Life Sciences Division of the NASA Office of Space Science and Applications. The Life Sciences Division has established the following programmatic goals: to ensure the health, well-being and performance of humans in space; to develop an understanding of the role of gravity on living systems in space; to expand understanding of the origin, evolution and distribution of life in the universe; and to promote the application of life sciences research to improve the quality of life on Earth.

1. Cosmos 2044

NASA's space medicine and biology programme has greatly benefited from scientific co-operation with the USSR on Cosmos missions through the opportunity to conduct experiments with animal subjects on the effects of long-duration flights. United States participation in Cosmos investigations is currently co-ordinated by the United States-USSR Joint Working Group on Space Biology and Medicine established under the United States-USSR Space Science Co-operation Agreement signed in April 1987. The Cosmos '89 (Cosmos 2044) mission was the seventh Soviet biostatellite mission in which NASA has participated.

More than 85 NASA-sponsored researchers from 19 states and three foreign countries participated in 29 co-operative investigations on the Cosmos biosatellite 2044 mission that was launched by the Soviet Union in September 1989. The Cosmos biosatellite is an unpiloted recoverable spacecraft that accommodates plant and animal experiments. Co-operative investigations on the 14-day Cosmos mission addressed questions relating to the biomedical effects of prolonged space flight. Biological specimens on the mission included rhesus monkeys, rats, fish, fish eggs, newts, drosophila, beetles, seeds, unicellular organisms and planaria. Investigations covered bone and muscle alterations, circadian rhythms and thermoregulation, neurophysiology, radiation biology and gravitational biology.

Nearly 3,000 biological samples were returned from the Cosmos '89 mission as were control groups of subjects. Data from the mission are currently being analysed in laboratories across the United States. The USSR has invited the United States to participate in co-operative investigations on a 1992 Cosmos mission. In reciprocal fashion, Soviet scientists have been invited to participate in analysis of specimens from the United States Shuttle Spacelab life sciences mission to be launched in 1990.

2. Spacelab life sciences missions

In 1989, planning continued for the first Spacelab life sciences mission (SLS-1). SLS missions are dedicated to understanding how living systems adapt to weightlessness. The 1990 SLS-1 mission will be the first Spacelab mission devoted to life sciences research. Both SLS-1 and SLS-2 will focus on early physiological responses to weightlessness such as acute fluid shift, cardiovascular adaptation and space motion sickness. Eighteen primary and 11 secondary payloads for SLS-1 have already been selected, including an experiment on the effects of weightlessness on human lymphocyte proliferation, sponsored by the Swiss Federal Institute of Technology, and another on the role of myosin isoenzymes and the alteration of muscles using the inflight monitoring and postflight tissue analysis of rats, proposed by the University of Sydney, Australia. Scientists anticipate that the SLS missions will increase confidence in their estimates of the physiological consequences of weightlessness, and will enhance their ability to manage and reduce its adverse effects.

Life sciences investigations will also be included as a part of international Spacelab missions such as the IML-1 and -2, the Japanese Spacelab-J, and the Federal Republic of Germany's Spacelab-D-2 missions. NASA life scientists have also been engaged in a project with France's CNES to design and develop a rhesus research facility for Spacelab use.

In 1989, NASA sent out research announcements for international participation on the IML-2 mission. One half of the IML-2 payload is directed by NASA and, of this portion, more than one half will be dedicated to life sciences investigations. Biomedical investigations accepted for definition on IML-2 deal with sleep physiology and human performance.

3. LifeSat

In January 1989 NASA's Johnson Space Center released a request for proposals for continued studies leading to the design and construction of an unmanned reusable re-entry satellite that will greatly expand NASA's capability to undertake extended duration studies in the weightless environment of space, particularly in the life sciences and microgravity sciences areas. When the satellite is carrying life sciences specimens it will be referred to as LifeSat. It will be launched by ELVs and be capable of staying in space for up to 60 days at a time. It will also be able to fly experiments in a number of different orbits, including those at a higher latitude than the STS/Spacelabs, which will create an opportunity to study the effects of more intense radiation dosages. Its design will then enable it to re-enter in a controlled soft landing at a predetermined landing site. Modules planned for LifeSat include a general biology module, a rodent module, and a botany module.

LifeSat will provide the opportunity to acquire data on relatively long-term space flight in unique environments. Over the long term, LifeSat will serve as a complement to the continuing Spacelab series of missions and the facilities on Space Station Freedom. The LifeSat concept has excited substantial international

interest in Japan, Canada, France, the Federal Republic of Germany and ESA. Parallel studies were conducted by NASA and potential partners during 1989 and will continue in 1990.

4. Extended duration orbiter programme

The EDO programme, a new start 1989 programme, is a reponse to the requirement to extend STS mission durations from a current maximum of 10 days up to 16 days for the 1990s. The extended flight times create physiological demands on the crew members that cannot be adequately assessed using current information. STS differs from previous spacecraft because the crew, while readapting to the Earth's gravitational field, must perform re-entry, landing and egress (including escape) operations that require proficiency and physical capabilities that were not needed before the STS era.

From previous STS flights, it has become apparent that new procedures and counter-measures need to be developed to ensure the safety and success of EDO missions. During the EDO programme a data base will be developed to define and understand the operational significance of flight-induced alterations in physiology. Procedures and counter-measures for optimizing crew performance for nominal and contingency entry, landing and egress during extended missions will be developed and verified. Emphasis will be placed on maintaining orthostatic tolerance, exercise capacity and sensorimotor function. Also, STS EDO environmental and monitoring requirements for air quality, water potability, surface contamination, radiation, waste management and general habitability will require upgrading. A significant part of the IML-2 payload will be dedicated to EDO programme studies.

5. Centrifuge facility programme

The 1.8-meter centrifuge facility includes a variable speed centrifuge; habitats for rodents, plants and small animals; a multi-purpose glovebox and workbench; and a specimen chamber resupply. The centrifuge facility will provide life scientists with the ability to vary gravitational force on a broad range of living species, under completely controlled conditions, for extended periods of time on Space Station Freedom. For the first time it will be possible to keep living specimens at gravity levels up to the level of gravity experienced on Earth, while at the same time exposing them to weightlessness and the other effects of space flight. Investigators will thus be able completely to distinguish physiological effects due to weightlessness and other characteristics of space flight. The centrifuge will also permit scientists to use gravity as an experimental variable. They will be able to alter the gravity level the organisms are exposed to, in order to discover how it affects physical functions like growth and development. The centrifuge may also make it possible to determine if artificial gravity is an effective counter-measure against the adverse physiological effects of prolonged time in space.

6. Controlled ecological life support system

Development of a regenerative life support system with enhanced efficiency for food production and waste recycling involves two for major basic and integrated functions; physical/chemical life support elements and biological life support elements in a system that is known as a controlled ecological life support system (CELSS). The Life Sciences Division is responsible for mission operational system requirements for both physical/chemical life support systems and for technology development for CELSS.

The CELSS programme was initiated on the premise that NASA's goals would eventually include extended-duration missions with sizeable crews requiring capabilities beyond the ability of conventional life support technology. Currently, as mission duration and crew size increase, the mass and volume required for consumable life support supplies also increases linearly. Under these circumstances, the logistics arrangements and associated costs for life support resupply will adversely affect the ability of NASA to conduct long-duration missions. A solution to the problem is to develop technology for the recycling of life support supplies from wastes. The CELSS concept is based upon the integration of biological and physico-chemical processes to construct a system that will produce food, potable water and a breathable atmosphere from metabolic and other wastes, in a stable and reliable manner.

Essential in CELSS development are investigations and technology development in the areas of plant growth, food processing, energy balance, waste processing, sensing, controls and automated systems. It must also be determined whether full size plants can grow productively in microgravity. In 1989, definition studies continued on the CELSS programme. NASA planning involved developing a ground-based CELSS within a decade; developing flight-certified hardware; pursuing opportunities to fly CELSS experiments; and ultimately designing a space-based CELSS system.

7. Search for extraterrestrial intelligence microwave observing project

Over the past 20 years, NASA has conducted extensive studies on the feasibility of carrying out a search for extraterrestrial intelligence (SETI). Other groups around the world also recognized the desirability of conducting such a search. A SETI microwave search was recognized at the United Nations UNISPACE 82 meeting at Vienna and was later recommended by the National Commission on Space. From 1983 to 1989, NASA's Ames Research Center and Jet Propulsion Laboratory jointly conducted an engineering development programme to design a SETI system capable of conducting an extended search of the microwave portion of the electromagnetic spectrum. In October 1989, NASA formally initiated the SETI microwave observing project as an element in the exobiology programme conducted by the Life Sciences Division.

The exobiology programme seeks to understand the origin, evolution and distribution of life in the universe. The microwave observing project is designed to address the hypothesis that life, including intelligent life, may be widespread

in this galaxy. It is generally agreed that a technically feasible and promising method of detecting extraterrestrial civilizations that are not currently within reach of spaceflight missions is by the detection of microwave signals they may be transmitting. The microwave observing project will carry out, through the 1990's, a systematic search of the terrestrial microwave window (1-10 GHz), where background radio emissions are at a minimum. The search systems will be very sensitive to an extended class of signals that are compressed in frequency and perhaps also in time and that, as far as is known, are not produced by other astrophysical processes.

F. Microgravity science and applications

NASA's microgravity science and applications (MSA) programme is conducted jointly through the Microgravity Science and Applications Division of the Office of Space Science and Applications and by the Office of Commercial Programs. The mission of NASA's Microgravity Science and Applications Division is to utilize the reduced gravity environment in space to conduct research in fundamental science, materials science and biotechnology. Other divisions of NASA, such as the Life Sciences Division, also conduct microgravity research, but not under the MSA programme.

Studies conducted under these unique conditions can help to clarify the roles of factors normally masked by or in competition with gravity-induced phenomena in complex physical processes. The resulting knowledge benefits both Earth- and space-based technology. The near elimination of gravity is also exploited to process selected materials in unique ways. For example, the extremely quiescent environment is conducive to the growth of larger and more perfect inorganic and protein crystals that can be grown on Earth. These and other high-value space processed materials may have important applications: e.g., in the development of new pharmaceutical products and advance engineering materials.

NASA welcomes the involvement of international partners in the microgravity science and applications programme by offering opportunities to foreign scientists to conduct research in space aboard United States spacecraft. Enrichment of the overall programme occurs through the sharing of both United States- and foreign-developed experiment hardware and by the sharing of scientific data. The international research community continues to play an important role in NASA's microgravity science and application programme through valuable interchanges with United States scientists in forums such as the International Microgravity Laboratory (IML) Science Working Group, and the IML Investigator Working Groups.

1. Ground-based microgravity science research

The primary functions of the Microgravity Science and Applications Division's ground-based research programme are to develop concepts that will lead to flight experiments; to determine limitations of various terrestrial processing techniques; and to provide analysis and modelling support to the flight programme. NASA supports its research programme by using specialized ground-based facilities to complement the limited number of Space Shuttle flight opportunities.

Microgravity science and applications research requirements have influenced the development of ground-based facilities with a variety of experimental capabilities. Drop towers, drop tubes and aircraft flying parabolic profiles constitute NASA's most important ground-based assets for the simulation of microgravity conditions. These facilities contribute significantly to the experimental advancement of microgravity science, even though near-weightless periods last only a few seconds. The availability and cost-effectiveness of these facilities relative to extended Shuttle flight opportunities make them useful in the advancement of scientific theories, evaluation of instrumentation and testing of prototype experiment hardware prior to flight. Additional ground-based testing capabilities are provided by expendable suborbital sounding rockets.

2. Flight-based microgravity science research

Presently, the Shuttle or STS is the primary United States platform for microgravity science research. Most of the flight experiment hardware currently being designed will be flown aboard the Orbiter, in locations in mid-deck and in dedicated pressurized laboratories in the Spacelab. Highly automated payloads may also be flown in special self-contained canisters known as "get-away-specials", in the cargo bay.

Typical STS missions of 7 to 14 days' duration greatly extend the time available for the conduct of microgravity experiments. These extended periods are needed to investigate more thoroughly a variety of phenomena which do not reach equilibrium in the short periods of microgravity afforded by specialized ground-based facilities. Studies ranging from the dynamic behaviour of fluids, to combustion and fire safety, to investigations of fundamental physical principles are planned in the microgravity science programme. The scope of the materials science research encompasses the processing of electronic and photonic materials; metals and alloys; glasses and ceramics; and polymers. The microgravity science research programme also includes biotechnology research in the areas of macromolecular cell growth, protein crystal growth and biological material separation techniques. To complement flight opportunities offered by the Space Shuttle, the use of alternate payload carriers such as free-flying spacecraft, orbital platforms launched by unmanned expendable vehicles, and suborbital sounding rockets, are also being examined.

In 1989, microgravity experiments supporting research in several scientific disciplines were flown aboard the Space Shuttle on flights STS-29, STS-30 and STS-34. Examples are given below.

A protein crystal growth (PCG) experiment package was successfully flown on STS-29 in March 1989. Employing a large number of small, individual growth chambers, the PCG apparatus exploits the extremely quiescent environment in space to grow larger and more highly ordered protein crystals than can be grown on Earth. X-ray diffraction methods are then used to resolve their three-dimensional molecular structures more finely than possible with the best Earth-grown crystals. Among the high-quality protein crystals grown on the STS-29 flight were elastase, an enzyme associated with the degradation of lung tissue in people suffering from emphysema, and isocitrate lyase, a target enzyme for the development of more effective fungicides.

STS-30, in May 1989, flew the fluids experiment apparatus (FEA) mid-deck payload developed by Rockwell International Corporation. This experiment evaluated the feasibility of applying float zone processes in space for the growth of crystals of high quality. Microgravity experiments, conducted by the Life Sciences Division, relating to the impact of the state of weightlessness on the human body and on the growth of plants were conducted on STS-34 in October. While some results of the 1989 Shuttle experiments are still being analysed, it is clear that significant scientific contributions were made in these fields. Information gained from these experiments is being applied in the related research programmes, and is also being used to improve the effectiveness of future flight hardware.

3. United States microgravity laboratory mission series

United States microgravity laboratory (USML) missions will offer United States investigators major opportunities to conduct microgravity research in space, using primarily United States-developed hardware. The mission will take place aboard dedicated, pressurized Spacelab laboratories. Four USML missions are scheduled, beginning in 1992 and continuing at approximately two-year intervals thereafter. NASA will provide the launch service, define and integrate the payloads, and maintain responsibility for mission management. The USML mission series complements NASA's IML missions, and is viewed as an essential stepping stone in the development of technology, hardware and operational procedures for microgravity science applications aboard the Space Station. In 1989, principal investigators, both United States and foreign, were selected to conduct flight research on the USML series.

Presently, the first USML flight represents the highest-priority near-term flight opportunity for United States microgravity experiments. Four major experiments, including the drop physics module, the crystal growth furnace, the surface tension-driven convection experiment and the solid-surface combustion experiment have been scheduled for that mission. Much of the Microgravity Science and Applications Division's efforts and resources, in 1989, were devoted to prepare the experiment hardware for USML-1.

4. International microgravity laboratory mission series

The IML mission series will extend major opportunities for microgravity research to the international scientific community. These missions will offer the use of predominantly foreign-developed hardware to both United States and foreign investigators. As with the USML series, NASA will provide the flight opportunities, define and integrate the payloads and manage the missions for the IML series. IML is specifically conceived as a laboratory research programme using multiple application instruments on frequent flights with minimal disassembling or modification between missions. It serves as a test bed for international Space Station co-operation in the microgravity science field.

Through six international space science research organizations, more than 200 scientists from 13 countries are collaborating with NASA on the IML-1 mission to provide the world-wide science community with a variety of complementary facilities and experiments. As of 1989, non-United States experiments and experimental hardware selected for IML-1 included: ESA's Biorack, which can be used to study the effects of microgravity and cosmic radiation on up to 150 types of plants, insects, tissues, cells and bacteria; the CNES-developed mercury-iodide crystal growth (MICG) facility for the study of the effects of gases on the nucleation of mercury iodied in microgravity; the space physiology experiments (SPE), which are a set of six experiments sponsored by the National Research Council of Canada to study how the human nervous system adapts to weightlessness; the organic crystal growth facility sponsored by the Japanese space agency; and a German contribution, the Cryostat, which is essentially a temperature-controlled protein crystal growth experiment. Payload specialists for the IML and USML missions will be actively involved in many of the investigations as trained scientists performing experiments on-orbit and providing scientific analysis of experiment progress to investigators on the ground. IML-1 is scheduled for flight aboard the Shuttle Columbia in 1990.

5. United States microgravity payload mission series

The United States microgravity payload (USMP) is an automated, unpressurized system resident in the Shuttle payload bay. It is an additional payload configuration, beside IML and USML, that will fly multi-user and experiment-unique equipment aboard the Space Shuttle periodically over at least the next six years. Use of the equipment aboard USMP experiment missions will provide precursors from which Space Station microgravity facilities will evolve.

Five USMP missions are currently scheduled through 1996. The first USMP mission (USMP-1) has been manifested for flight aboard STS-51 in 1992. USMP-1 experiments include: the advanced automated directional solidification furnace (AADSF), which will be useful for investigations into the roles of gravity-induced phenomena in the growth of crystals; and the "Lambda Point" experiment (LPE), developed at Stanford University in conjunction with NASA's Jet Propulsion Laboratory. This experiment will very accurately determine the heat capacity of a liquid helium sample as it repetitively traverses its transition point under microgravity conditions. This important experiment will test the limits of validity of the group renormalization theory, dealing with the universality of the behaviour of matter near critical phase transition, which earned a Nobel prize for its author in 1982.

6. Microgravity science and applications programme aboard Space Station Freedom

The microgravity science and applications programme currently looks beyond the Space Shuttle to other research platforms, including SSF. The Space Station will provide a stable platform on which highly productive and flexible microgravity science experiment modules can be based. A key long-term programme goal remains the development of several multi-user facilities specifically designed for long duration scientific research missions aboard SSF.

In 1989, NASA continued feasibility studies of and defined initial requirements for six multi-user facilities for the Space Station Freedom: the Space Station furnace facility (SSFF); the modular containerless processing facility (MCPF); the advanced protein crystal growth facility (APCGF); the biotechnology facility (BTF); the modular combustion facility (MCF); and the fluid physics/dynamics facility (FPDF). These facilities will each accommodate a variety of investigations in several critical scientific disciplines well suited to space experimentation. Although their design requirements are currently evolving, they will be modular and readily adaptable to the needs of individual investigators for many years. The facilities will be transported to SSF over an extended time-frame beginning in the mid 1990s. Operation of the first facility, APCGF, will begin in 1996.

G Communications and information systems

NASA communications research focuses on developing and demonstrating microwave, optical and digital technologies to increase the capacity, flexibility and interconnectivity of future space communications systems.

1. Mobile satellite communications programme

NASA is engaged in supporting United States industry in the introduction of a commercial mobile satellite system (MSS). MSS would enable individuals in moving vehicles such as cars, ships and airplanes, to communicate directly through satellites using specialized omnidirectional antennas on the vehicles. Since 1982, NASA has been involved in the development of critical technologies and validation studies for MSS, that are known collectively as the mobile satellite experiments (MSAT-X).

In 1989, MSAT-X scientists were able to perform two significant mobile satellite demonstrations. The first demonstration was a NASA/Federal Aviation Administration (FAA) aeronautical mobile satellite communications (AMSAT) demonstration which used the NASA-developed terminal hardware, an FAA aircraft, and the INMARSAT Atlantic Ocean Satellite (MARECS-2B). With the support of FAA and INMARSAT, MSAT-X scientists were able to demonstrate full aeronautical mobile communications during flights along the eastern coast of the United States. Four thousand eight hundred bits/second digital voice and data communications were maintained even in regions where terrestrial voice between the aircraft and ground was lost. Flight traffic controllers indicated that the voice through the MSAT link was acceptable. This was the first full AMSAT demonstration with this technology.

The second demonstration was the first land mobile satellite communication demonstration using a geostationary satellite. With the use of ETS-V provided by Japan and with the hub and ground support of Australia's AUSSAT, MSAT-X scientists were able to demonstrate the two-way digital voice and data in a true land mobile satellite environment. As a result of this demonstration, AUSSAT has decided to implement digital rather than analog for mobile satellite communications voice and data.

The implementation of the United States mobile satellite services moved ahead in 1989 with the Federal Communications Commission licensing of mobile satellite services to the American Mobile Satellite Corporation (AMSC) on 31 May 1989 and the release of a joint AMSC/Telesat Mobile (Canada) request for proposals for MSS spacecraft.

2. Advanced communications technology satellite

ACTS planned for launch in May of 1992, is a key element in NASA's communications programme, whose goal is to develop advanced communications satellite technology to support the United States future telecommunications needs. The success of this programme will allow growth in the capacity and effective utilization of the frequency spectrum and will maintain the pre-eminence of the United States in satellite communications.

The NASA ACTS programme sponsors the development and flight testing of high-risk advanced communications satellite technology including:

(a) Multibeam antennas, providing a rapidly reconfigurable pattern of hopping beams and fixed spotbeams;

(b) A high-speed baseband processor that increases capability relative to current technology by routing individual message circuits onboard the satellite;

(c) A dynamic, reconfigurable microwave switch capable of routing high-volume, point-to-point and point-to-multipoint traffic;

(d) Ka-band (30/20 GHz) transmission components for satellite and ground segment equipment;

(e) Advanced network control algorithms to provide flexible, efficient demand-assigned multiple-access communications;

(f) Adaptive compensation for signal level changes due to rain, including forward error-correction and uplink power control to adjust automatically for fades.

The ACTS scanning spot-beam satellite provides qualitatively different communications capabilities compared with conventional satellites or terrestrial networks. The combination of high-gain multibeam antennas, producing fixed and scanning spot beams, and the baseband processor, which provides switching and message routing, permits unique communications performance in public and private networks.

In 1989, the ACTS Programme Office defined a number of broad applications areas so that the resources of the experiments programme may be focused and effectively exploited. These applications areas represent the most maximizing use of the ACTS technologies and include the following fields: video, mobile (including aeronautical, vehicular, and maritime), high data-rate, integrated services digital network (ISDN), public and private networks, NASA science networks and military applications.

3. Search and rescue satellite-aided tracking programme

The SARSAT programme was initiated by NASA in the 1970s. The programme in the United States is a joint venture that involves NASA, NOAA, the United States Coast Guard and the United States Air Force. Internationally, the programme is known as COSPAS-SARSAT. The space segment consists of two operational United States satellites, as well as two operational satellites provided by the Union of Soviet Socialist Republics. Stations located in 10 countries comprise the ground segment. Radio transmissions, from beacons used in emergency situations, are intercepted by the orbiting satellites that form the constellation and are redirected to the appropriate ground station for data processing. The critical information is relayed to the rescue co-ordination centre. To date, the COSPAS-SARSAT programme has been instrumental in saving over 1,400 lives.

NASA is responsible for the United States SARSAT research and development. During 1989, NASA scientists successfully demonstrated the ability of GEOS to detect instantaneously distress beacons without position location. A geostationary interferometer is being investigated to provide simultaneous detection and position location for distress beacons.

NASA is also investigating feasibility of using multispectral scanning techniques to locate beaconless crash sites. During 1989, NASA SARSAT scientists successfully located a crashed aircraft in the desert using multispectral scanner data.

4. Telemedicine spacebridge

For four months during the summer of 1989, NASA communications and information systems and life sciences divisions in co-operation with the Soviet Ministry of Health, implemented a "Telemedicine spacebridge" experiment which provided satellite video, voice, facsimile, and telex links between Soviet and United States medical teams for treatment of Armenian earthquake victims. The experiment was conducted under the auspices of the United States/Union of Soviet Socialist Republics Joint Working Group on Space Biology and Medicine and was considered by participants to be highly successful. The earthquake, which occurred early December 1988, caused more than 150,000 casualties as well as widespread destruction estimated at $20 billion to $40 billion. Provision of the initial satellite communications links was made possible by a co-operative effort with the COMSAT Corporation, INTELSAT, AT&T, Satellite transmission and reception specialists, and NASA's Goddard Space Flight Center in the United States, and the Soviet Ministry of Post and Telecommunications.

The United States physicians and specialists that participated in the spacebridge project provided consultative support to more than 200 Soviet physicians primarily in the areas of reconstructive surgery, rehabilitation and psychiatric care for post-traumatic stress disorder. Participating United States centres were: (a) the Uniformed Services University of the Health Sciences in Bethesda; (b) the University of Maryland Institute of Emergency Medical Services Systems, Baltimore; (c) the University of Texas Health Science Center, Houston; and (d) the Latter Day Saints Hospital and the University of Utah, Salt Lake City.

In June, during the administration of the spacebridge, NASA was met with an urgent request from the Soviet Ministry of Health to provide technical assistance to medical experts treating victims of a gas explosion near the city of Ufa in the Ural region of the Soviet Union. Twelve hundred casualties resulted when sparks from a passenger train ignited gas escaping from a ruptured line nearby.

In response to this request, NASA extended the Armenian spacebridge project to include black-and-white slow-scan video and voice communications between Ufa and Yerevan for retransmission through the spacebridge to the United States, where the same hospitals provided medical consultation to burn specialists in Ufa. This equipment was used because it quickly established simple-to-operate links using existing terrestrial voice circuits and infrastructure not capable of accommodating full-motion video. It enabled transmissions of photo images of the burn victims, taken by Soviet physicians, as well as audio teleconferencing.

The quick response to this request was made possible by an intensive co-ordinated effort by SOYUZMEDINFORM, a division of the Soviet Ministry of Health, the Soviet Ministry of Posts and Telecommunications, and the Public Service Satellite Consortium of Washington, which implemented the system on behalf of NASA. The slow-scan video transceivers were donated by Colorado Video, Inc. of Boulder, Colorado.

An important outgrowth of this programme has been increased awareness among medical, technical and political leaders of the application of satellite communications to disaster medicine.

V. SPACE TRACKING OPERATIONS

A. Completion of the tracking and data relay satellite system

In March of 1989, the third Tracking and Data Relay Satellite (TDRS-D) was deployed from the Space Shuttle Discovery, marking the completion of the baseline TDRSS. All three TDRS spacecraft operate in geosynchronous orbit and communicate with a NASA ground facility located at White Sands, New Mexico. This White Sands ground terminal (WSGT) is operated by CONTEL, Atlanta, Georgia, under contract to NASA. When supporting low-Earth orbiting spacecraft, TDRSS allows for additional communications opportunities as compared with the old ground network of tracking stations with an increase from 15 to 85 per cent coverage per orbit. It will also allow for significantly higher rates of data transmission.

TDRS-C was successfully deployed from STS-26 in September 1988, and placed at its geostationary location of 171°W longitude, south of Hawaii. TDRS-D, after its deployment from STS-29, was boosted by an upper stage to geosynchronous altitude and replaced TDRS-A at 41°W longitude, east of Brazil. TDRS-A was relocated to 79°W longitude and became a spare resource to serve as a backup in the event of a failure in either operational satellite. After testing the baseline configuration, TDRSS was declared operational in October 1989. TDRSS is capable of simultaneously relaying data from up to 23 low-Earth orbiting spacecraft, depending upon their transmission data rates.

B. Deep-space network tracking of Voyager 2 Neptune encounter

Voyager 2 is controlled and its data returned through DSN, a global spacecraft tracking system operated by the Jet Propulsion Laboratory for NASA. DSN antenna complexes are located in California's Mojave Desert, near Madrid, Spain, and in Tidbindilla, near Canberra, Australia. Each DSN complex has three antennas that may be used to communicate with Voyager 2 or other distant spacecraft.

Shortly after the Voyager 2 Uranus flyby in 1986, the three largest (210 feet in diameter) and most sensitive antennas of DSN were systematically stripped of their surfaces and rebuilt to create an even larger (230-foot) receiving area for the incoming signal from the August 1989 Neptune encounter. Critical additional telecommunications support for the Voyager encounter of Neptune was provided by the Australian Government's 64-metre (210-foot) Parkes Radio Observatory near Canberra, Australia, which received Voyager data simultaneously with the Australian DSN complex. This technique, called arraying, greatly increased the data return from the Voyager 2 Neptune encounter. In addition to the antenna array in Australia, the twenty-seven 25-metre antennas of the National Radio Astronomy Observatory's Very Large Array (VLA) near Socorro, New Mexico, was arrayed with the California DSN station. The 64-metre (210-foot) Usuda Tracking Station, owned by the Institute of Space and Astronautical Science of Japan, provided additional tracking during critical radio science observations during Voyager's closest approach to Neptune and Triton.

C. Deep-space network tracking of Magellan and Galileo

As with Voyager, commands for controlling the Magellan and Galileo spacecraft are sent to the respective spacecraft via a single beam of radio signals from the antennas of NASA's DSN complexes. The Galileo command memory of 43,000 8-bit words can provide the spacecraft with enough instructions to carry out a sequence of tasks over a period ranging from days to months, depending on their complexity.

DSN will be retrieving data from the Magellan and Galileo missions respectively. Magellan will start mapping Venus in late 1990. Galileo, on the other hand, will not arrive at Jupiter until December 1995; nevertheless, data will be received through DSN from Galileo's flybys of Venus and the Earth as it uses these planetary bodies for gravity assists.

D. Goldstone solar system radar - exploration of Titan

In the summer of 1989, scientists at the DSN complex at Goldstone, California were able to take advantage of being linked for the first time, as part of support for the Voyager II Neptune encounter, to the 27 antennas of the National Radio Astronomy Observatory's VLA in Socorro, New Mexico. Using the Goldstone station as a radar transmitter and the VLA network in New Mexico as a receiver, scientists confirmed for the first time ever detection of a radar echo from the Saturn moon Titan.

Previously, it was believed that Titan was an ocean of liquid hydrocarbons, such as ethane and methane, that would not reflect radar and provide an echo signal. Astronomers were unsure of exactly how to explore Titan. Radio signals beamed to the planetary body, however, detected a reflected echo at certain longitudes of Titan, showing that the previous theory did not hold for the entire planet. Indeed, at some longitudes of Titan there is a reflecting surface. Now it is believed that the Titanian surface is analogous to that observed in data received on the Galilean satellites of Jupiter. The Cassini programme will use such data to receive enhanced information on Titan.

VI. SPACE RESEARCH AND TECHNOLOGY

A. Space research and technology programme

The primary goal of the space research and technology programme is to develop advanced technologies that enhance and enable future United States space missions. To achieve this goal, a commitment has been made to conduct a broad-based research activity which constantly advances the state-of-the-art in technology at the concept, subsystem and system level; to develop technical strengths in the engineering disciplines within NASA, industry and academia; and to perform critical flight experiments in areas where testing in the space environment is necessary for technology development.

In this effort, NASA will develop the technology, capability and infrastructure (a) to monitor and study our own "spaceship" Earth; (b) to return to the moon with a permanent manned lunar research base; and (c) to mount a sustained set of manned exploration missions to the planet Mars culminating in a permanent manned base there. In addition to the manned exploration, a vigorous unmanned programme to explore the solar system in detail with robotic explorers is to be pursued.

The space research and technology programme to accomplish these important national space goals is structured into five technology thrusts: space transportation, space station, space science, exploration and breakthrough. In addition, a key element of the space research and technology programme is developing and sustaining a strong partnership with the university community. The goal of the university space research programme is to enhance and broaden the capabilities of the nation's engineering community through active participation in the United States civil space programme. The programme is an integral part of the strategy to rebuild the space research and technology capabilities of the nation.

The transportation thrust of the programme addresses those technologies that will provide safer and more efficent access to space while reducing the overall costs associated with space launches. They will contribute to the design of a new fleet of space vehicles, including new expendable and partially-reusable cargo launch vehicles; fully-reusable manned vehicles; and expendable and reusable space transfer vehicles. In some cases, it will also provide additional capability for existing launch vehicles.

The space station thrust will provide those technologies for the current and evolutionary Space Station, including the technology base for future developments for exploration. This thrust addresses those technologies that will expand capability and reduce life cycle costs of the initial Space Station Freedom, enhance capability as a transportation node for the future space exploration initiative, and enhance Space Station capabilities as a testbed to conduct future technology development and validation.

The science thrust will provide technology for Space Science programmes focused on the planet Earth, the solar system and beyond. This thrust supports technology efforts to expand capability and reduce costs through disciplinary advances which increase science information return and spacecraft performance and enable the next generation of space science missions.

The objective of the exploration thrust is to develop the critical technologies required for future solar system exploration missions including establishment of an outpost on the Moon and exploration of the planet Mars. This effort will develop a broad set of technologies that will enable new and innovative capabilities, increase reliability and reduce risk for human missions beyond low Earth orbit, reduce development and operations costs for long-term exploration efforts and enhance performance for human and robotic missions.

The breakthrough thrust explores advanced concepts with the potential for revolutionary or major evolutionary advances. The focus of this thrust is to explore advanced high-risk, high-payoff technologies that have the potential to revolutionize the approach to future programmes.

Within these thrusts the space research and technology programme is composed of two complementary parts: the research and technology (R&T) based programme and the focused technology programmes. The R&T base serves as the seedbed for new technologies and capability enhancement. Through the R&T base programme, and usually in at a sub-scale level, scientists and engineers develop forecasts regarding the potential applicability, usefulness and overall benefit associated with new technologies. Once the potential applicability and usefulness of a new capability is documented, decisions are made to carry selective discoveries into focused technology.

Three focused programmes have been initiated since 1988: the civil space technology initiative, the exploration technology programme (formerly called Pathfinder), and the in-space technology experiments programme. In the focused programmes, technologies are developed for specific applications and products are delivered in the form of large-scale technology demonstrations, demonstrated hardware, software and design techniques and methods. Focused development is most often initiated based on the identified needs and potentials of both current and future programmes and missions identified to fill the needs of the technology thrusts.

This technology development is the vital first step in providing the capability to move out from Earth and expand our presence into the solar system. Significant progress was made in 1989 in each of the principal thrusts and continuing efforts promise to show even greater results.

B. Civil space technology initiative programme

Recognition of the need to expand and revitalize the United States civil space technology base led to the initiation of the civil space technology initiative (CSTI) in 1988. CSTI's primary focus is the development of technology to support efficient, reliable access to, and operations in, Earth orbit, and science missions conducted from Earth orbit. CSTI will develop specific technologies critical to the accomplishment of near-term, high-priority national space goals.

In the transportation area the main goal is to provide a significantly strengthened technology base for the design, development, management and operation of high performance, long-life propulsion systems. The aeroassist flight experiment will investigate critical vehicle technologies and upper atmosphere characeristics applicable to the development of an aeroassisted orbital transfer vehicle (AOTV). The use of an AOTV to perform aerobraking or orbital capture offers the potential for doubling of useful payload compared with conventional engine-firing.

The area of operations is being addressed in a number of significant ways by the CSTI programmes. Artificial intelligence is being developed and introduced into space transportation systems operations, science mission planning and execution and to increase real-time decision-making capability. Telerobotic capabilities are directed towards reducing the need for humans to perform dangerous, repetitive and boring tasks and are being developed for in-space assembly, transportation servicing and in-space servicing activities.

An example of a 1989 accomplishment in artificial intelligence is the real-time data systems, sapcecraft health automated reasoning prototype (SHARP), an expert system designed to monitor the condition of interplanetary spacecraft and ground operations. SHARP demonstrated a significant leap in automation technology during the tough operational environment of Voyager mission operations during the summer of 1989 encounter with the planet Neptune. The SHARP system automatically confirmed that a problem existed in attempting to recover and process data from the Voyager transmissions from Neptune, then defined the magnitude and aided in the determination of the problem cause to a specific failed electronic unit on the ground which was replaced. Using traditional methods, this process of problem identification and isolation would have been both laborious and time-consuming.

Science technology requirements addressed by CSTI are concerned with space data acquisition, manipulation and management, both in orbit and on Earth. Particular emphasis is currently being placed on the development of increased sensitivity and spectral range for earth-observing and astrophysical missions, on advanced mechanical cryogenic coolers with sufficient lifetime and capability for the next generation of science missions and on advanced data-processing capabilities to capture, process and archive the enormous volumes of data that will be generated by missions already planned.

C. Exploration technology programme

The exploration technology programme, which was started in the Fall of 1988 as the Pathfinder programme, implements the President's national space policy directing that we begin to plan for future solar system exploration missions. The exploration technology programme will develop the critical technologies that are required to enable missions that expand human presence and activity beyond Earth orbit into the solar system. On 20 July 1989, President Bush challenged the nation to set forth with a renewed commitment to exploration: "First for the 1990's, Space Station Freedom. Then, for the new century, back to the Moon. And this time, back to stay. Then, a journey into the future, a journey to another planet. A manned mission to Mars."

The exploration technology programme is a critical step supporting that presidential directive by establishing a foundation of technology for these future missions of exploration. The exploration technology programme, as a partnership between NASA, industry and academia, will enhance our nation's "cutting edge" in the highly competitive arena of aerospace technology. The exploration technology programme is developing new technologies in several broad areas to enable future robotic and piloted solar system exploration: surface exploration, in-space operations, humans in space, space transfer, lunar and Mars science, information systems and automation and nuclear propulsion.

During 1989, the first year of the exploration technology programme, significant initial progress was made in a number of key areas. The exploration technology programme supports NASA's contribution to the ongoing United States space nuclear power research and development programme, the SP-100 programme. In 1989, the SP-100 project, which is a joint NASA, Department of Defense and Department of Energy endeavour, successfully completed key irradiation-based accelerated life testing of reactor fuel pin elements. With no appreciable swelling of the fuel pins even after 5 per cent fuel burn-up, the testing demonstrated that lifetimes of seven years should be achievable with SP-100 technology: a critical step towards bringing this important technology to maturity for application at a lunar outpost early in the next century.

In 1989, the exploration technology programme planetary rover effort completed fabrication of two experimental mobile robot concepts: a multi-chassis, six-wheeled rover concept and a six-legged walking rover concept. These experimental robots will form the foundation for continuing development of mobile robotics software and navigation systems that will support future exploration of challenging - but scientifically intriguing - areas of both the Moon and Mars.

In the area of human presence in space, an innovative exercise facility was completed at the NASA Ames Research Center, which will be used to determine the human metabolic response to orbital extra-vehicular activity (EVA) work. The facility incorporates a controlled-atmosphere chamber, an EVA-work exercise device, which duplicates upper body movements in zero-gravity conditions, human metabolic instrumentation to monitor blood pressure, body temperature, respiration rates, CO_2 and H_2O expiration and oxygen intake. Human metabolic responses to simulated EVA work will be obtained so that thermoregulatory control methods may be designed to

reflect more accurately the EVA work requirements resulting in increased astronaut comfort within a space suit, particularly for increased EVA missions approaching eight hours.

In space propulsion in 1989, the first successful operation of a compact, high-speed liquid oxygen turbopump with a gaseous oxygen (GOX) drive was achieved. This type of turbine-pumping liquid but driven by gas is crucial to the development of a high-performance expander cycle engine critical to deep space exploration.

Both CSTI and the exploration technology programmes are envisioned as multi-year efforts with strong participation by all NASA centres. The programme is built on the concept of a strong partnership between NASA, United States aerospace industries and United States universities.

VII. SPACE COMMERCIALIZATION

There is increasing recognition, both in the United States and abroad, that space has attributes that are of great value. These resources and characteristics will play a major role in opening a new economic frontier for the spacefaring nations of the world.

The United States Government believes that an expanded and aggressive private sector investment in space-related activities will generate economic benefits for the nation and for the governmental space sector by creating a wide range of new goods and services, and that it will help to keep the United States on the cutting edge of space technology in an increasingly competitive international commercial space environment.

It is clear that commercial development of space is both a logical progression in the United States civil space efforts and a prudent competitive strategy. NASA's Office of Commercial Programs, created in 1984, is the focal point for the agency's efforts to stimulate and assist expanded involvement and investment by the United States private sector in civil space activities. OCP also helps to bring about the commercial application of space technology.

Among the initiatives undertaken by the Office of Commercial Program's commercial use of space programme to reduce the technical, financial and institutional risks of doing business in space are sponsorship of 16 non-profit centres for the commercial development of space (CCDS) - university, industry and government consortia for high-technology research and development with potential commercial applications and innovative working agreements that allow commercial users access to government facilities and expertise on a favourable reimbursement basis. The Office of Commercial Programs also fosters commercial interest in space by accelerating the transfer and use of NASA-generated technology to private industry through its technology utilization programme. In addition, the small business innovation research (SBIR) programme is managed by the Office of Commercial Program, seeking to involve small, innovative businesses in research that could lead to commercial space ventures.

A. Commercial development of space strategic planning

True commercial space is achieved when industries are established that generate new products and services for private markets. Development of these new products and services will, in turn, support the growth of other commercial space industries, such as transportation and infrastructure. One of NASA's goals is to help the private sector to develop commercial space as a new sector of the national economy.

The Commercial Programs Advisory Committee (CPAC) was established to provide NASA with continuing advice on the proper roles and responsibilities of Government and industry in the commercial development of space. CPAC is composed of corporate chief executive officers and university presidents.

In 1989, CPAC published its report, "Charting the course: United States space enterprise and space industrial competitiveness," which summarizes the results of its first year of work. It proposes nine key recommendations that executive branch leaders, government agencies and the Congress can implement to foster United States space enterprises and space industrial development. NASA is currently reviewing these recommendations to determine appropriate action.

Also supporting the Office of Commercial Program's strategic planning effort, in 1989, was a study conducted by the American Institute of Aeronautics and Astronautics (AIAA) to lay the groundwork for the strategic plan by defining issues and potential objectives associated with the commercial development of space. AIAA formed a steering committee consisting of senior-level private sector managers. The resulting study document, "Issues in strategic planning for commercial space growth," representing inputs from more than 90 industrial representatives, addresses overall goals and objectives, the scope of commercial space activities and the role of industry, academia and the Government; explores issues and barriers; and suggests federal actions and policy changes.

B. Commercial use of space programme

The development of new products and services, especially those involving materials processing of life sciences, requires long-term industry commitment. There are a number of barriers to this development (such as the high upfront cost of assessing space) which can be insurmountable for firms conducting research and development that may or may not yield returns years in the future. NASA's CCDS programme is one of the mechanisms targeted towards overcoming these obstacles to market development.

The CCDSs, which form the cornerstone of NASA's assistance to private-sector commercial space initiatives, are a network of 16 competitively selected consortia of university, industry, and other non-NASA government organizations performing the early research and testing phases of potentially commercially viable technologies. Through a grant programme, NASA provides the initial financial backing needed for the applied technology phase, while academia and industry provide the market-driven approach necessary to bridge the gap between applied research and commercial

application. This approach will ultimately result in large-scale industry involvement in developing space-related technologies. These industry-driven technologies could, in turn, lead to a broad range of new markets and services.

The 16 CCDSs involve the active participation of 175 companies and 52 universities. Industry has demonstrated its commitment by investing heavily in this co-operative programme. For example, the average ratio of industry matching funds (measured in cash and in-kind services) to government funding for the 16 CCDSs, is approximately 2.2 to 1. The ratio of just the first five CCDSs, established by NASA in 1985, has risen to 3.4 to 1.

C. Commercial development payloads

A resurgence of industrial research and development activity took place in 1989 following the successful return of the Space Shuttle to flight operations in 1988. In 1989, the Office of Commercial Programs sponsored commercial development payloads on three Shuttle missions. Commercial experiments flown on the Shuttle included:

(a) Protein crystal growth, an experiment package flown by the NASA-sponsored Center for Macromolecular Crystallography located at the University of Alabama in Birmingham, aboard STS-29 in March. The experiment, conducted in collaboration with industrial partners, also will be flown on STS-32 for further flight testing;

(b) Fluids experiment apparatus (FEA), flown on STS-30 in May 1989 and is scheduled to fly again on STS-32. FEA, a modular microgravity chemistry and physics laboratory, is being flown under a NASA-Rockwell International Corporation joint endeavour agreement (JEA) in the field of floating zone crystal growth and purification research;

(c) Polymer morphology, a 3M Corporation-developed organic materials processing experiment, was designed to explore the effects of microgravity on polymeric materials as they are processed in space. The experiment, conducted on STS-34 in October 1989, was 3M's fifth space experiment and the first under the company's 10-year JEA with NASA for 62 flight experiment opportunities.

In an effort to match commercial space transportation and support capability with the anticipated growth in industry requirements, NASA in 1989 provided augmented grant funding to the CCDSs for a commercial sounding rocket programme. Consort 1, a package of six CCDS-developed payloads was launched successfully on 29 March atop the commercially provided Starfire rocket at White Sands Missile Range, New Mexico. Consort 1 was the first flight conducted under this effort. Eight members of United States industry, three CCDSs and four universities were involved in the project. The suborbital flight provided seven minutes of microgravity.

The entire effort commercially to procure the Consort 1, including payload launch services, integration and recovery of the payloads took only 9 months, compared to the traditional 18 to 24 months. It demonstrated that the universities

and industry can move quickly to develop commercial opportunities for space research in a highly efficient and successful manner, with minimum government involvement and at a moderate cost.

Consort 2, launched on 15 November 1989 at White Sands, was only a partial success due to a malfunction in the rocket's guidance package, resulting in termination of the mission as the rocket strayed off course. The payloads, recovered undamaged, will be launched again at a later date.

D. Technology development

Sixty-one new technologies have been defined by the CCDS, many of which are expected to mature as economically useful applications. Extensive ground tests have proven the need for further flight testing of these technologies. Since the inception of the CCDS programme, the following experiments have been completed towards technology development: 935 drop tube/drop tower experiments; 12 Lear/KC-135 flights, 15 payload flight tests aboard 2 sounding rockets; and 5 flight tests aboard the Space Shuttle. Through these experiments, industrial researchers obtained valuable data that contributed to decisions as to whether or not future flight tests were warranted.

The technologies under development at CCDSs are recognized as "new" by the industrial space community. Eighteen patents have been granted to the CCDSs on their work while 41 more patent applications are awaiting confirmation. CCDSs have generated close to 800 technical publications in refereed journals, with 91 more in the pipeline.

E. Co-operative agreements

The co-operative agreements administered through the Office of Commerical Programs during 1989 represent another facet of government/industry co-operation in the commercial development of space. For example, a memorandum of understanding was signed with Corabi International Telemetrics, Inc., supporting the commercial development of telemedicine services for the Space Station Freedom. Coca-Cola also entered into a memorandum of understanding with NASA in support of the firm's investigation of fluid dynamics, gas-liquid separation and metering technologies in space. Two firms, Global Outpost, Inc., and the University Corporation for Atmospheric Research, were selected in 1989 to hold further discussions on their proposals for the commercial development of expended Space Shuttle external tanks in suborbital or orbital flights. Agreements were also signed with LTV Missiles and Electronics Group, Martin Marietta Commercial Titan, Inc., and Conatec, Inc., to provide assistance, services and facilities in support of the development of a commercial ELV industry.

F. Technology utilization programme

The technology that NASA develops to meet its research and programme goals represents an important national resource. The NASA technology utilization programme spreads this valuable technology throughout the economy by working with United States industry to adapt space technology to meet its needs. NASA, through this long-standing program, has maintained a systematic approach for identifying space technologies that may have useful application in the non-space sector of the economy.

The technology utilization programme involves both technology dissemination and technology application. Technology dissemination requires the identification and gathering of information on aerospace technologies making this information available to the private sector. Technology application is the use of these NASA technologies in specific projects for public benefit.

The 1989 edition of NASA's annual Spinoff magazine documented spinoff products resulting from secondary applications of NASA-developed technology in such areas as public safety, the environment, medicine, consumer/home/recreation, computer technology and industrial productivity. A recently completed study assessing the economic impacts of NASA technology transfer activities (specifically spinoff products) indicated substantial financial benefits to United States businesses. More than 400 secondary technology applications reported in the magazine between 1978 and 1986 were traced, and 342 applications resulted in acknowledged contributions to sales or savings. About 75 per cent of those applications provided some quantification of those sales or savings - $21.3 billion in sales of new or improved products and nearly $316 million in savings. It was also calculated that the revenues produced through the estimated sales generated federal income tax revenues of nearly $356 million, and 352,000 job were created or retained due to the increased revenues (not savings).

In response to congressional interest, NASA initiated a study in October to determine whether the Stirling engine technology could be a long-term solution to the nation's automotive emission problem. The study addresses whether a commercial demonstration is the logical next step; the optimal federal agency long-term sponsor; the distribution of private (and public) financial contributions; and mechanisms for securing funds. Completion of the report is projected for spring 1990.

G. Small business innovation research programme

The Office of Commercial Programs has management responsibility for the SBIR programme which plays an important role in the Office of Commercial Program's commercial development programme. SBIR programme objectives, established by law, include stimulating technological innovation in the private sector, strengthening the role of small businesses in federal R&D programmes, fostering and encouraging greater participation of minority and disadvantaged businesses in technological innovation, and increasing private sector commercial development of innovations derived from federal R&D.

Participating agencies support the SBIR objectives by reserving a statutory percentage (1.25 per cent) of their extramural R&D budgets. This reserve is awarded to small business concerns for R&D during the first two phases of a uniform, three-phase process. Since the inception of the programme in 1983, NASA has awarded 1,243 phase I contracts (including 251 during 1989) to determine the feasibility of innovative concepts proposed by small business. The 251 phase I awards made in 1989 were selected from more than 2,140 phase I proposals received. Of the nearly 1,000 phase I projects that have been completed to date, 510 have been selected for further development under phase II contracts. The 100 phase II selections made in 1989 were for continuation of phase I projects completed in 1988.

VIII. INTERNATIONAL SPACE YEAR

In 1989 planning accelerated for the observance of International Space Year (ISY) in 1992 with a strong programme of activity by the Space Agency Forum for International Space Year (SAFISY). At a meeting in Italy in April, SAFISY adopted 10 Mission to Planet Earth projects that were developed by a NASA-convened panel of experts on Earth science and technology in February in Abingdon, England. The projects address environmental issues of immediate concern - greenhouse effect, deforestation, ozone depletion, etc. - and also establish standards and procedures for broader long-term application. Significant progress was made in the ISY Mission to Planet Earth projects during the second half of 1989, with planning meetings in several countries in preparation for an overall review in early 1990.

At the twenty-sixth session of the United Nations Scientific and Technical Sub-Committee of the Committee on the Peaceful Uses of Outer Space in February 1989, the United States submitted document A/AC.105/C.1/L.160. This working paper proposed a substantive role for the United Nations in ISY. The United States proposal called for the United Nations to capitalize on the educational and training capabilities of the United Nations Space Applications Programme of the Outer Space Affairs Division as well as the unique advantages of the UNEP Global Resources Information Database (GRID) system. The proposal called for a training course in 1991 as well as a workshop and conference in 1992.

In December 1989, the United Nations General Assembly endorsed ISY (see General Assembly resolution 44/46) and offered to contribute through activities that focus on education and training for developing nations. The United Nations activities will complement and sometimes be co-ordinated with applications activities under development by SAFISY. The International Astronautical Federation (IAF) highlighted ISY at its annual Congress in Torremolinos, Spain, and initiated planning with COSPAR for a jointly sponsored World Space Congress in Washington, in 1992, dedicated to ISY.

The United States welcomed the 1989 United Nations endorsement of ISY, and it has been active in setting its own agenda for ISY activities. In July 1989, the United States International Space Year Association (US-ISY) and NASA sponsored an all-day symposium at the National Academy of Sciences in Washington at which ISY was introduced to representatives of national associations with broad public constituencies and major multinational corporations. Also in 1989 NASA and the

French CNES sent out invitations for a conference in February 1990 that would lead to the establishment of an education and applications panel of experts and the development of proposals for a SAFISY meeting in April 1990 in Japan. At the same time, COSPAR of the International Council of Scientific Unions (ICSU) initiated a space science panel of experts at SAFISY's request.

IX. SPACE RESEARCH OPPORTUNITIES

A. Announcements of opportunity

The United States has made virtually all of its civil spacecraft projects, both flight and ground-based, open to domestic and foreign scientific participation on a co-operative basis. Foreign proposals received in response to research announcements by the NASA International Affairs Division will go through the same evaluation and selection process as United States-originated proposals. In the case where a foreign proposal is selected, NASA will arrange with the sponsoring foreign agency for the proposed participation on a co-operative (no exchange of funds) basis, in which NASA and the sponsoring agency will each bear the cost of discharging their respective responsibilities.

B. Experiments with non-United States investigators

Non-United States scientists, working in their own laboratories, may participate in NASA co-operative space missions as principal or co-investigators through the provision of scientific experimental hardware, the analysis of relevant mission or supporting data, or both. The participation of such principal investigators is noted in the sections concerning individual projects.

C. Scientific and technical information exchange

NASA has scientific and technical information document exchange agreements with some 220 organizations in 43 countries. Special document exchange arrangements exist with more than 75 organizations involved in space research or related activities. NASA also manages world data centres for data from NASA satellites, as part of the world-wide system organized by ICSU to facilitate international scientific data exchange.

Under a special arrangement with the Information Retrieval Service (IRS) of ESA, NASA makes its scientific and technical aerospace reports (STARs) and international aerospace abstracts (IAA) files available to IRS. Qualified European organizations that have completed a tripartite agreement with NASA and IRS have on-line access to these files in exchange for one technical report for each hour of on-line access time. At the end of 1989, there were over 500 organizations in 17 countries participating in this programme.

NOAA's National Oceanographic Data Center supports international activities through programmes of the Intergovernmental Oceanographic Commission (IOC) and

other international bodies. NOAA also manages world data centres for data from NOAA satellites on oceanography, meteorology, solar-terrestrial physics, glaciology, marine geology and geophysics and solid Earth physics. In 1989, NOAA provided technical information on satellite operations to over 3,000 foreign academic and amateur institutions. In addition, NOAA/NESDIS Satellite Direct Readout Services provides environmental data to over 5,000 stations around the world.

D. Education and visits at NASA and NOAA facilities

Post-doctoral and senior post-doctoral grants are available to qualified non-United States scientists for participation in research at NASA centres, NOAA laboratories, and NASA's Jet Propulsion Laboratory. The principal international exchange activity conducted by NASA is the resident research associateship programme, administered for NASA by the National Academy of Sciences. This programme provides for post-doctoral research for one year at NASA installations in the scientific fields of astronomy and astrophysics. In addition, NASA provides technical training for foreign scientists and technicians in support of agreed upon co-operative programmes.

Numerous officials and scientists from around the world visit NASA and NOAA installations each year for general orientation or information exchanges on space programmes and related research. Also, a substantial number of foreign visitors attend launchings.

In 1989, 183 senior foreign scientists participated in the resident research associateship programme, 8 foreign nationals received technical training at NASA centres, and over 5,500 foreign visitors from 100 countries and organizations visited NASA facilities. NOAA awarded 14 grants in 1989 as part of the resident research associateship programme, of which at least 4 were related to space data applications. In 1989, NOAA also initiated and co-ordinated long-term international technical training for over 38 international trainees from 23 countries. Over 50 international trainees participated in co-operative short-term training courses which were conducted by NOAA.

E. International summer student programme

The international summer student programme is designed to encourage youths from other countries to pursue careers in aeronautics and space activities by offering opportunities for foreign students to work at NASA field centres during the summer months. The programme began in 1983 and has had student participants from Australia, Brazil, Canada, Chile, the Federal Republic of Germany, India, Indonesia, Italy, Japan, Mexico, Morocco, New Zealand, Senegal, Spain and the United Kingdom.